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Statistical Analysis of Inter-Yarn Friction and Structural Changes in Treated and Finished Fabrics

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Abstract: A significant challenge in the industrial growth of textiles is the production of sustainable and green products of fabrics with modified inter-yarn friction, possessing the least inclination toward structural changes during fabric finishing processes. Therefore, this study aims to investigate the effects of paraffin wax treatment and finishing processes on inter-yarn friction and mechanical changes in treated and untreated fabrics. The interplay between the treatment and finishing processes demonstrates the critical role of frictional forces in determining the mechanical behavior of the fabric. Additionally, employing paraffin wax on the fabric surface assisted in refining the structural properties, improving the surface smoothness, and improving the surface fiber uniformity with modified inter-yarn dynamics. The research findings indicated that paraffin wax treatment significantly altered the fabric tensile strength, tear strength, hydrophobicity, and durability. Hence, this research provides valuable insights for optimizing inter-yarn interactions to achieve the desired performance metrics, including tensile strength, durability, and surface aesthetics. The results obtained from the paraffin wax treatment showcase the exclusive development of advanced treatment processes in the textile industry to enhance tailored mechanical and structural characteristics.

Keywords: Inter-yarn Friction, finishing treatment, Paraffin Wax, Woven Fabric, contact angle, water absorption, sustainable practices.

1. Introduction

1.1 Overview of the Textile Industry

Textile and clothing industries are one of the largest revenue-generating industries of any agricultural country. The extensive job opportunities provided by these firms become a source of employment across numerous developed countries [1]. Manufacturing in the textile industry, which is a main type of the industrial diversification, is classified into three main categories: cellulose fibers, protein fibers, and synthetic fibers. The composite of textiles is extensively used across various departments such as marine vessels, biomedical, and other fields due to its excellent properties, such as high strength, lightweight structure, specific modulus, and structural designability [11]. Additionally, the mechanical characteristics of fabrics are the primary component of fiber reinforcement [2]. In addition, the friction modes are highly influenced by the contact behavior of fiber, which also involves the deformation of the fibers. However, yarn friction is considered highly complex, involving various phenomenon and mechanisms, as the composition of yarn is based on thousands of fibers that may be easily damaged by twisting and sizing the fibers, without employing preventative or precautionary measures [13]. The fabric's finishing process is highly critical in the manufacturing of textiles, as it relatively enhances the aesthetic and functional characteristics of the fabrics [3]. The finishing stage involves employing treatments that should not be overlooked to achieve specific quality standards of the fabric, such as resistance to wrinkles, durability, softness, and water absorption. According to Islam et al. the mechanical finishing techniques involve calendaring and mercerizing to improve the aesthetics of the fabric [3]. The application of chemical agents such as flame-retardant treatment or anti-wrinkle finishes involves altering the physical properties of the fabric, known as chemical finishing.

Additionally, alongside relative industries, the textile industry actively focuses on enhancing sustainable finishing to reduce environmental waste and showcase process sustainability in the process [4]. Research study conducted by Shim et al. discusses the mechanical properties that refer to the fabric's ability to withstand external force [5]. The strength of the fabric is considered one of the most important factors, defined as the ability to resist fiber damage or breakage, despite external force or tension [3]. Additionally, fabric extensibility is the process that showcases post-fiber breakage to determine the fabric's extent of stretchability. On the contrary, tensile modulus calculates fabric stiffness or rigidity that requires dimensional stability under external

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stress (e.g., in outerwear and technical textiles). Moreover, the potential capacity of the fabric to withstand wear from the rubbing process and abrasion resistance is a crucial mechanical characteristic used in upholstery, flooring, and activewear [7]. Alongside mechanical properties, physical properties describe the behavior of the fabric in response to environmental changes and conditions. Fewer essential physical properties contribute to enhancing fabric performance, for instance, moisture management, thermal properties, and weight. According to Yilma and Limeneh, the fabric's absorbance capacity refers to the absorbability, release, or transport moisture in the moisture management property [10]. The fabric that is designed with moisture-wicking properties is more comfortable than other fabrics. The process of weaving on a loom makes it possible to interlace the warp and fill threads in a pre-arranged manner [30]. The performance of the fabric in terms of physiological sensorial comfort ought to be an important requirement for the textile industry [9]. In addition, thermal properties constitute as a major factor that influences the production of sustainable fabrics. Furthermore, the weight of the fabric impacts its usability and comfort level, as lighter fabrics are often used as summer apparel. Hand-feel value (HF) can be measured on the TS value, depending on the thickness and weight of the fabric [8]. Another parameter, inter-yarn friction, which is the result of the fiber's intrinsic frictional characteristics, fabric structure, and surface treatment, is crucial to assess the physical and mechanical properties of the fabric. Therefore, the research aims to investigate the effects of paraffin wax treatment and finishing processes on inter-yarn friction and structural changes in treated and untreated fabric samples. The finishing treatment of paraffin wax utilized in the study aims to effectively alter fabric compactness while increasing inter-yarn friction. As a result, this intervention aimed at enhancing tensile strength while reducing the fabric's tear resistance.

1.2 Problem Statement

The textile industry is directed towards improving fabric performance through various innovative treatments and finishing processes. Among these, the paraffin wax treatment significantly aims to modify the physical properties of woven fabrics. Despite the extensive use of paraffin wax treatment, a significant gap yet exists with regards to investigating the specific impact of paraffin wax treatment on the inter-yarn friction of woven fabrics. Along with the increasing need for high-performance textiles in sectors like fashion, automotive, and technical applications, the understanding of trade-offs connected with paraffin wax treatment becomes essential to manufacturers in optimizing fabric properties while meeting consumer demands. This research investigates the effects of paraffin wax treatment and finishing processes on inter-yarn friction and structural changes in woven fabrics.

1.3 Research Significance

This study bridges a critical gap in the understanding of how paraffin wax treatment and finishing processes affect woven fabrics' mechanical properties. The main purpose of this research is to investigate these effects, especially how the treatment of paraffin wax influences the compactness of fabric, porosity, inter-yarn friction, tensile strength, and tear resistance [6]. These findings are crucial for several reasons, such as the textile industry is continuously being challenged in terms of fabric durability and performance under various conditions. Conversely, increased friction may adversely affect tear resistance, an important property for many end-use applications. As time passed, the textile industry felt more pressured to adopt sustainable practices because a huge amount of waste had been produced in the fabric manufacturing procedures from the beginning till the end. To resolve this issue, paraffin wax is already known for its protective qualities, which could reduce the need for frequent replacement and repairs and move towards a more sustainable lifecycle of textile product making.

1.4 Research Hypothesis and Objectives

This study is based on the hypothesis that paraffin wax treatment alters the surface characteristics of woven fabrics in a way that increases inter-yarn friction and tensile strength, enhances hydrophobic behavior, and may reduce tear resistance due to decreased yarn slippage.

Accordingly, the specific objectives of this research are:

1. To investigate the influence of paraffin wax treatment on inter-yarn friction and fiber compactness within woven fabrics.
2. To measure the resulting changes in mechanical properties, including tensile strength and tear resistance.
3. To assess the treatment's impact on surface-level hydrophobicity through contact angle and water absorption behavior.
4. To compare the performance metrics of treated and untreated fabric samples under standardized testing conditions.

2. Literature Review

2.1 Commonly Used Treatments

The incorporation of wax emulsion in the textile industry marked a significant shift in fabric treatment technology, especially in finishing treatments [14]. The process of wax emulsion is composed of a variety of mixed wax, such as paraffin wax, water, and emulsifiers, that aim to enhance the fabric's tactile qualities by improving inter-yarn friction and structural changes. The utilization of paraffin wax is considered one of the most emerging finishing techniques, along with the chemical coating that collectively aims to enhance and improve water resistance, aesthetic appeal, and durability of the fabric. In the same sense, there are several advantages of wax emulsion in the textile manufacturing industry, such as durability enhancement, water repellency, resistance to stains, and a softening effect that provides ease in the finishing process of fabric [15]. The variety of treatment processes introduced in the textile industry has increased the urge to enhance the fabric's durability and strength. On the other hand, it also increases the pressure on textile manufacturers and industrialists to enhance their fabric performance and quality so that they stay in the market longer [16].

2.1.1 Paraffin Wax

Paraffin wax treatment is one of the most well-established methods for water repellency on fabrics. The treatment consists of a layer of paraffin wax applied to the surface of the fabric [6]. This layer aims to provide a barrier to moisture and improve the durability of the fabric. In addition to that, the technique of applying melted paraffin wax to the uniform coating on the fabric surface through means of pad dry cure or sprays is implemented. The piece of fabric gets cured under warm temperatures to stick well to its fibres.

2.1.2 Chemical Coating

Chemical coatings refer to the application of chemical substances on fabrics to impart specific functional properties. This treatment can enhance several features, such as stain resistance, flame retardance, and antimicrobial properties [17]. The detailed process of chemical coatings uses a technique that is applied through padding, spraying, or foam application techniques. The application usually requires a curing process to fix the chemicals in the fabric to make them last longer and have higher strength and durability.

2.2 Finishing Processes in Textiles

The finishing processes range from various treatments that are designed to transform the properties of the textiles to meet and fulfil the specific needs of users and consumers [18]. This study also discussed various finishing techniques and their impact and influence on fabric performance after finishing touches. The process of finishing can be categorized into various methods, but a few important processes were discussed in the study, such as mechanical, chemical, and thermal treatment, which majorly contributed to the distinct characteristics of the fabric.

2.2.1 Mechanical Finishing

The mechanical finishing technique involves physical methods that alter the fabric structure without the external addition of any substance or chemical. Table 1 describes the techniques used in the mechanical finishing, alongside their fabric after the finishing procedures.

2.2.2 Chemical Finishing

The process of applying chemical agents on the surface of the fabric for the achievement of desirable qualities of the fabric requires the application of chemical finishing [19]. Table 2 discusses the used techniques and impacts of chemical finishing on the fabric properties.

2.2.3 Thermal Finishing

The process of thermal finishing involves the heating properties that require altering the fabric properties with the use of chemicals on the surface of the fabric. Table 3 describes the technique and impact of thermal finishing on the fabric.

Table 1: Mechanical Finishing

Mechanical Finishing	**Description**	**Impact**
Singeing	A process that involves passing the fabric through a flame to burn off protruding fibers, resulting in a smoother surface	Reduces pilling and enhances fabric appearance; improves dye uptake.
Calendaring	It involves passing the fabric through heated rollers to create a smooth, glossy finish.	It increases fabric density and smoothness, enhances luster, and reduces porosity.
Mercerizing	A treatment where cotton fabrics are soaked in a caustic soda solution, followed by rinsing and neutralizing.	Improves strength, dye affinity, and luster; enhances fabric durability and reduces shrinkage.

Table 2: Chemical Finishing

Chemical Finishing	**Description**	**Impact**
Water Repellent Finishes	Chemical treatments impart hydrophobic properties, allowing fabrics to resist water and stains.	Enhances durability by preventing water penetration, thus prolonging fabric life.
Stain Resistance	Specific chemical agents are used to reduce fabric absorbency, preventing the penetration of stains.	Improves maintenance by making fabrics easier to clean and maintain, catering to consumer preferences for low-maintenance textiles.
Antimicrobial Treatments	Chemicals are applied to limit bacterial growth, enhancing hygiene in textiles used in healthcare and sports.	Increases comfort and performance by promoting hygiene and reducing odor in activewear and medical textiles.

Table 3: Thermal Finishing

Thermal Finishing	Description	Impacts
Heat Setting	This process stabilizes the fabric structure, preventing further shrinking and wrinkling, which is common in synthetic fibers.	Improves dimensional stability, ensuring that products retain their intended shape after washing or wearing.
Flocking	A heat-activated adhesion process that bonds short fibers to the base fabric, creating a velvety finish.	Adds aesthetic appeal by providing a luxurious feel and surface texture, enhancing the overall appearance of the fabric.

2.2.4 Eco-friendly Finishing

As the textile industry is emphasizing on sustainability, eco-friendly finishing procedures are introduced and adopted at larger scale. Table 4 discusses the techniques and impact of eco-friendly techniques on the fabric finishing methods.

Table 4: Eco-friendly Finishing

Eco-friendly finishing	Description	Impact
Biobased Coatings	Utilizing natural substances for coatings can impart properties like synthetic chemicals while being less harmful to the environment.	Enhances environmental compliance by being less toxic and biodegradable, meeting regulatory requirements and consumer demand for sustainable products.
Foam Finishing	This method reduces water and chemical usage compared to traditional pad methods, making it more sustainable.	Improves consumer acceptance as environmentally conscious consumers prefer fabrics treated with sustainable methods, influencing marketability.

2.3. Mechanical Properties of the Finished Fabric

2.3.1 Tensile strength

The tensile strength of the yarn fabric is represented by the greater loss that can be sustained without breaking the sample when subjected to uniaxial tensile loading [20]. Additionally, tensile strength is one of the most significant mechanical properties of the fabric, and it ensures the durability, comfort level, and life span of the textile products. According to Malik et al., woven fabrics are considered elastic and anisotropic as their mechanical properties are determined by the complex combinations of fiber bundles, stacking sequences, yarn spacing, and yarn sizes. The mechanical properties of the woven fabric provide extra resistance to damage and very high strain towards the failure while experiencing tension and comparison, mostly due to the interlacing of the fiber bundles. Additionally, an important parameter that describes the fabric structure expressed in the percentage is the difference between the entire length of fiber (L_0) and its length when it is weaved within the structure of the fabric (L_1) of the entire fiber length. However, the abrupt decrement in the load after the tensile strength is a sign of progressive yarn failure [12].

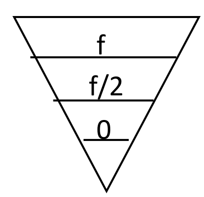
$$\text{Crimp}=\frac{L0-L1}{L0}\text{x}100$$

The assessment of tensile strength is commonly performed by a standardized test namely the Grab test that is based on the procedure in which the sample fabric is clamped at both ends and pulled until it breaks to measure the maximum load. Secondly, the strip test which is also like the Grab test but focuses on the fabric strips' strength over a greater length in order to provide more extensive fabric performance under stress [21].

2.3.2 Tear Resistance or Tear Strength

The coating of the surface of the fabric has affected its tear resistance or tearing strength with the help of coatings of laminates on the top surface of the fabric, which is the most common approach to protect the fabric. According to Eltahan, the ability of the material to resist a tear or breakage until the least count of the composition is crucial to maintaining and increasing the structural integrity of the fabric [23]. To protect the fabric from tearing, different coatings based on liquid or gaseous form are applied on the surface to provide pigment, flame retardance, and water mildew resistance. However, the application of coatings like PU and PVC can efficiently enhance the tear resistance of the fabric by providing an additional protective layer, which ensures less fabric integration over time [24]. The process of examination of tear resistance can be performed using the tongue tear method or the trapezoid tear method, as both examination tests are applied to better characterize the tear resistance properties [23].

The mechanism of the tear strength test can be explained as follows:



The del shape represents a number of threads subjected to the force of tearing; the first thread is under all the force applied to it, and the following threads share in the force applied till the last thread, at which the effect of force is dissipated. So, the average force applied on threads in the del is *f/2*and the tearing strength can be calculated as:

Tearing strength = No. Of threads in the del ×f/2

Then, whenever there is mobility and ease between thread and slide, the tear strength will increase. The effect of tearing strength is subjected to either one of two parameters. 1. the increase in density and the increase of fabric tightness will lead to high inter-yarn friction and low inter-yarn assistance, which will result in low yarn slippage and, thus, low tear strength. 2. the effect of paraffin wax, which acts as a lubricant agent, will cause easy yarn slippage, thus high tearing strength.

2.3.3 Hydrophobicity

The hydrophobicity is the ability of the material to repel water. The opportunely coated surfaces of the fabrics generated a water-repellent surface, which has lower surface tension, especially on the exterior phase of the fabric. According to Sfameni et al., the use of modified sols with suitable hydrophobic substituents results in superhydrophobic and water-repellent films that can be achieved in a single-step procedure [25].

To measure the hydrophobicity of the fabric, several testing methods were introduced, such as Contact angle measurement used to measure the angle formed between a falling droplet of water and its contact with the fabric surface. The drop of the water deposited on surfaces, such as superhydrophobic fabric, exhibited extremely high contact angles (>150) and showed rolling and slight inclination [26].

Another test called the Spray test, involved spraying water onto the fabric to observe the beading behavior of the woven fabric. Additionally, the wetting time test is dependent on the time taken for the water droplets to penetrate into the fabric to indicate that the shorter wetting time is recognized as the lower hydrophobicity of the fabric and requires further finishing coating [27].

2.3.4 Durability

The durability of the clothing refers to the length of service provided by the fabric or tenure of the product during its usage time period [28]. In the context of fabric, durability is categorized into two types, namely physical durability and emotional durability. The physical durability of the woven fabric is defined as the construction and strategies reinforcement in order to generate products that have the ability to resist damage even after several wears [29]. On the other hand, the emotional durability of the fabric is translated in terms of its design, patterns, and colors, which also showcases the fabric's quality to stay relevant and desirable to the consumer [28].

3. Methodology

The samples were analyzed for the warp and weft density and yarn count. The tensile strength, tear resistance, wetting behavior (hydrophobicity), and durability of the fabric were measured with different devices. The results obtained were illustrated in figures and curves to be compared with each other to study the effect of finishing and the effect of treatment with paraffin wax on the physical and mechanical properties of the treated and untreated fabric.

3.1 Fabric Specification

Two fabric samples were received, with all samples possessing similar weave structure. The two samples are finished fabrics; however, Sample 1 is treated with paraffin wax while Sample 2 remains untreated.

3.2 Fabric Samples Testing

Different testing apparatuses are used to perform physical and mechanical tests, where both samples are analyzed to obtain different results. All the tests were carried out according to ASTM protocols.

3.3 Warp and Weft Density

A magnifying glass was used to obtain the warp and weft densities, through which the number of ends and picks withing one centimeter distance were counted.

3.4 Contact Angle

When a droplet of water is dropped on the surface of a fabric, the contact angle between the droplet and the surface can be measured using the same instrument used in measuring the sliding angle. The readings are not precise but relative to each other to show the increase or decrease in water contact angle from one specific fabric to another. The diameter of the droplet used in measuring the contact angle of the samples was estimated to be one centimeter.

Fig. 1: One-centimeter water droplet

3.5 Tensile and Tear Strength

The tensile strength test was conducted to measure the force that was required to break or tear the fabric. After the wax coating procedure, the tensile strength of the woven fabric increased [23]. Another test, named the tear strength test, is used to measure the force required to continue the process of tearing the fabric. As a result, the characteristics of fabrics, such as flex abrasion resistance, yarn knittability, sew ability, and softening of the fabric, improved by the paraffin wax finishing treatments.

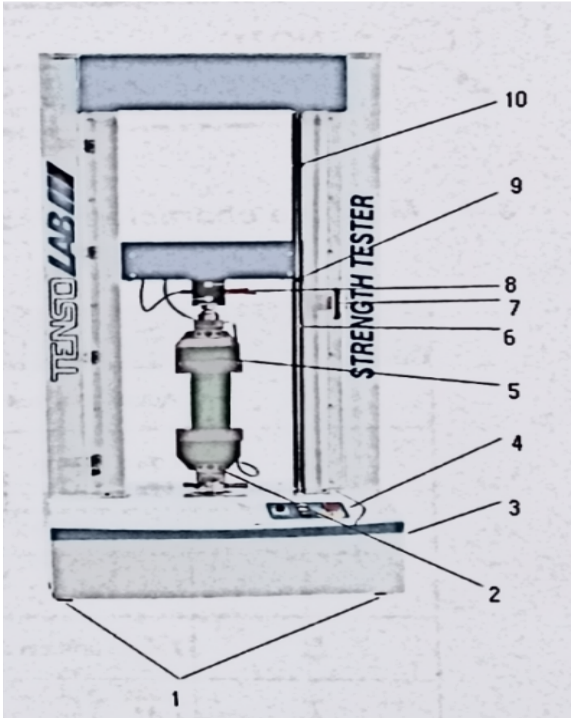


Fig. 2: Tensolab Instrument

A tensolab instrument was used to perform both tests: tensile and tear strength. The instrument consists of several key components such as adjustable feet, lower clamp, side panel for connections, control panel, upper clamp, target, zero excursion, protection panel, load cell, machine zero limit, and upper safety limit. The movement principle of the test is CRE (Constant Rate of Extension). To perform the test, the specimen is fixed in the upper and lower clamps; the upper clamp starts to move upward gradually at a constant rate, and once the specimen breaks, the value of force applied is recorded. The specimen dimensions according to the standard ASTM D5035 for tensile strength test is (20*3.5) cm. The specimen dimensions according to the standard ASTM D2261 for tear strength test is (20*7.5) cm.

3.6 Treatment of Samples

Some of the above-mentioned samples were treated with a mixture of two liquids. The two liquids are named; Clear Lacquer Spray as a bonding agent and Air Freshener Spray as a hydrophobic agent.

The contents of Clear Lacquer Spray are:

1. Waxes < 5%
2. Solvent
3. Hydrocarbons 5:15%
4. Silicones 5%
5. Formaldehyde < 5%
6. Perfume
7. The contents of the Air Freshener Spray are as follows.
8. Fragrance 0.3:2%
9. Octadecyltrimethyl Ammonium Chloride 0.01:0.05%
10. Potassium Dihydrogen Orthophosphate 0.1:0.5%
11. Disodium Phosphate 0.1:0.5%
12. Propane 1:15%
13. Butane 10:20%

The samples were treated with the two liquids by spraying them uniformly on the sample and then left to dry for 24 hours at room temperature. After drying, the tests were carried out. The tests that were carried out were tensile and tear strength and water absorption. Data were analyzed and compared.

3.7 Treatment and Finishing Processes

One of the effective processes that has gained traction in the recent years of development in the textile industry is the usage of paraffin wax in the fabric finishing processes and for wax-coating textiles. The composition of the paraffin wax is based on the mixture of saturated hydrocarbons (alkanes) that were obtained as a byproduct of lubricant oil. The paraffin constituted about 15% of the weight of the crude and required isolation from the oil to avoid crystallization at low temperatures [32]. Around 80-90% linear chains (n-paraffin) with 20–30 carbons,2,3, and oil-branched chains (iso-paraffin) consisted of alkanes present in the composition of paraffin wax.

According to El-Dalatony et al., the usage of paraffin wax in the fabric finishing treatment minimizes its inter-yarn friction, which simultaneously increases the mechanical strength of the woven fabric [33]. Paraffin wax has been dedicated use in the textile industry because it combines its physical (melting or freezing point, hardness or penetrability, and viscosity), functional (impermeability, flexibility, and adhesiveness), and chemical properties (color, odor, light, and heat stability) [34]. The process of applying paraffin wax to fabrics consisted of several crucial and detailed steps that required precision and time for the achievement of efficient results [35].

1. Before applying the wax, precautionary measures should be taken at the prior level, such as washing and cleaning the fabric. The process of washing involves the removal of contamination in the form of any impurities, residues, or dyes that may cause adhesion to the wax treatment procedure. After the process of cleaning and drying, the fabric is ready for the optimal application of the paraffin wax.

2. The paraffin wax is typically heated to its melting point, which is around 60°C or 140°F in a controlled environment. After melting the wax, it achieved the desirable liquid form to ensure evenly distribution all over the fabric.

3. The application procedure consisted of several steps such as dipping of the fabric in a bath of melted wax that allow a thorough absorption of wax, spraying application to provide more even coating especially for the large and huge batches of the fabric, lastly brushing for smaller and minute precision as it allows precise control on a large coverage on the top and bottom surfaces of the fabric.

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4. After all these steps discussed above, the wax-coated fabric is cured to ensure that the wax adheres evenly and equally. The process of curing involved air-dying or external heat to set the wax on the upper layers of fabric without penetration to form a durable waterproof barrier.

4. Results and Discussion

The finishing process has an effect on different physical and mechanical properties of the fabric. After finishing, there would be changes in warp and weft density, fabric weight and thickness, porosity, water contact angle, tensile and tear strength, and other properties. The transform effect due to finishing and using paraffin wax as treatment, the difference, whether increase or decrease in values, were illustrated in figures and curves and discussed for better comprehension and comparison between the treated and untreated fabric samples.

4.1 Fabric Properties

4.1.1 Effect of Treatment on Warp and Weft Density

According to the Table 5, Sample No.1 represents the sample before treatment with the paraffin wax. Sample No.4 represents the same sample after treatment. Each of the samples has different warp and weft densities and different thicknesses. The above table shows the effect obtained by the treatment on yarn count and weight. The effect obtained by the treatment on yarn count and weight is also clear in the above table. The density of warp and weft of sample No.1 has not been influenced by the treatment of the paraffin wax, as it has the same number of ends and picks per centimeter after treatment. The same behavior was observed with sample No.4 after treatment. The increase in yarn thickness due to the addition of wax made the fabric count constant, and this is the reason for the fabric count not being affected by treatment.

4.1.2 Effect of Treatment on Warp and Weft Count

After the paraffin wax treatment, the warp and weft thread count in Sample 4 decreased, as compared to Sample 1. Since the metric count is an indirect system, this decrease indicates that the threads became coarser after treatment. The increase in yarn coarseness is attributed to the addition of wax. Additionally, the warp thread counts in Sample 4 showed irregular behavior, which could be due to the uneven distribution of wax. Overall, the treatment resulted in a coarser fabric with fewer threads per unit area.

Table 5: Warp density, weft density, fabric weight, and fabric thickness

Sample	ends/cm	picks/cm	Nm (warp)	Nm (weft)	Weight (gm/m2)	Thickness (mm)
1 (untreated)	17	10	6.67	8.08	447	1
2 (treated)	10	10	5.48	4.9	618	1.05

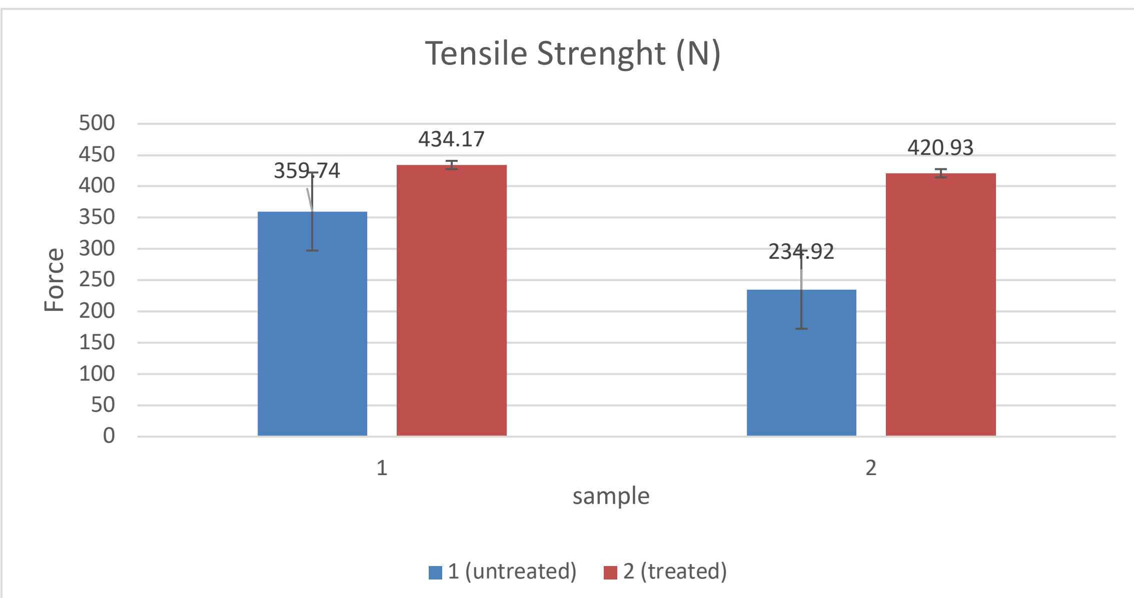


Fig. 3: Tensile strength of the samples

Table 6: Tensile Strength

Sample	Tensile Strength (N)	
	Warp	Weft
1 (untreated)	359.74	234.92
2 (treated)	434.17	420.93

4.1.3 Effect of Treatment on Tensile Strength

According to Table 6, the tensile strength of the warp threads is more than that of the weft threads due to the sizing of the warp threads. This may also be a result of the yarn count, which is coarser in the case of warp threads than weft threads. In the case of warp threads, the tensile strength of Sample 1 (Untreated) is less than that of Sample 4 (Treated). The warp tensile strength of sample 1 was 359.74, which increased to 434.17 N after treatment. Similarly, for weft threads, the tensile strength of Sample 1 was 234.9, but after the treatment, it increased up to 40.93 N. These results indicated that the paraffin wax treatment increases the tensile strength of warp threads. The increase in warp tensile strength is due to the fiber assistance achieved by yarn binding and inter-yarn friction, which enhances the fabric's resistance to breaking along a single line perpendicular to the extension force.

4.1.4 Effect of Treatment on Tear Strength

Table 7: Tear Resistance

Sample	Tear Strength (N)	
	Warp	Weft
1 (untreated)	59.74	29.66
2 (treated)	110.01	109.63

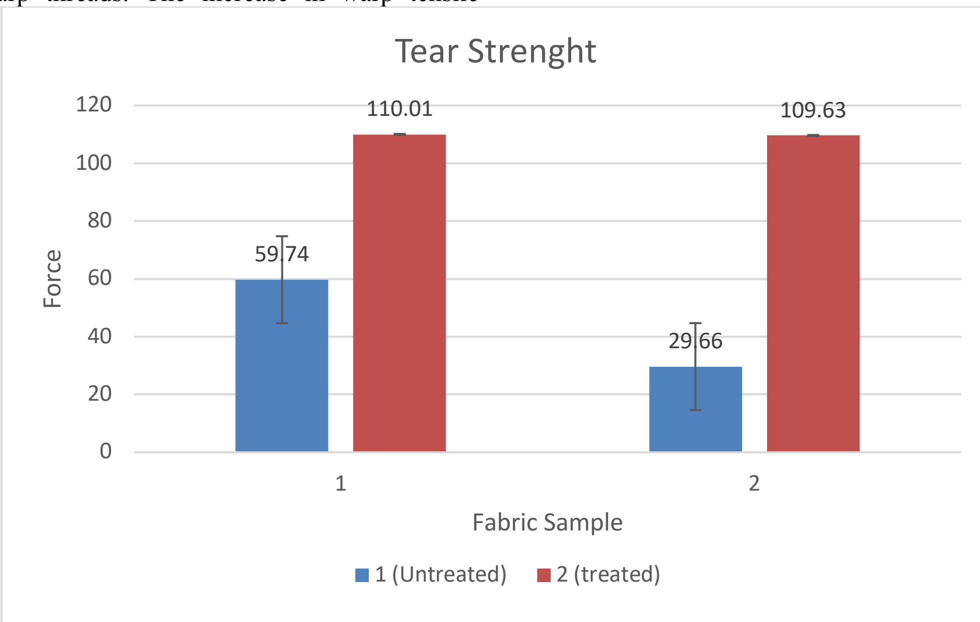


Fig. 4: Tear strength of the samples

According to Table 7, the tear strength of the warp threads is greater than that of the weft threads due to the sizing of the warp threads. This may also be a result of the yarn count, which is coarser in the case of warp threads than weft threads. The paraffin wax was also found to enhance abrasion resistance with an improvement in the tear strength of the fabric and flex abrasion resistance [36].

In the case of warp threads, the tear strength of Sample 1 (untreated) is slightly higher than that of Sample (treated). The tear strength increased from 59.74 N to 110.01 N, reflecting a significant difference. For weft threads, the tear strength of Sample 1 (untreated) is lower than that of Sample 2 (treated). The tear strength decreased from 29.66 N to 109.63 N, showing a considerable difference. This analysis indicated that the paraffin wax treatment had a varying effect on tear strength, with warp threads showing an increase while weft threads exhibited a decrease. The change in tear strength may be intended to serve a specific end use of the treated fabric. After the application of paraffin wax, the tear strength of the treated fabric decreased, and this reduction was observed in both warp and weft threads.

4.1.5 Effect of Treatment on Contact Angle

Table 8: Contact Angle

Sample	Contact Angle (°)
1 (untreated)	98
2 (treated)	115

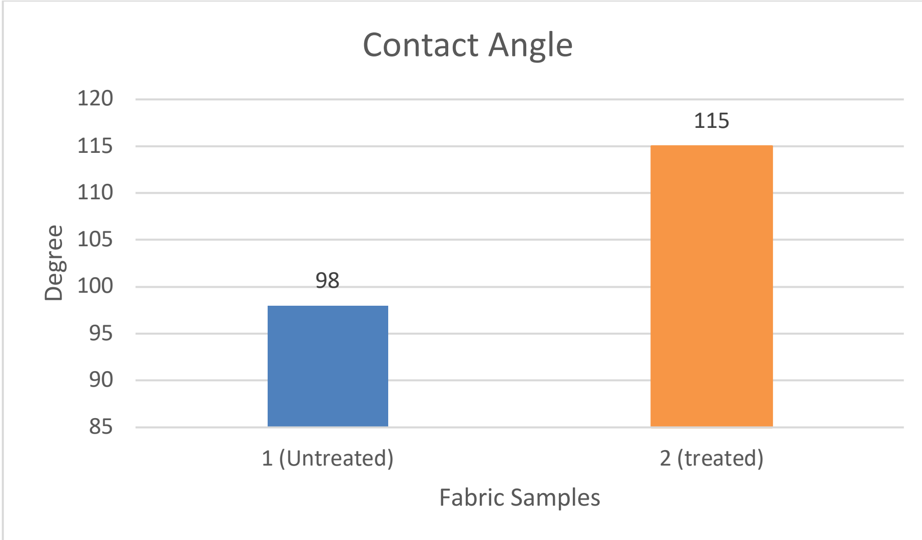


Fig. 5: Contact angles of the samples

Table 9: Water Absorption

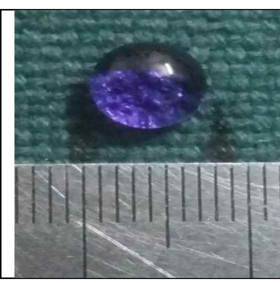
Time	0 secs	30 secs	60 secs
Sample No.1 (untreated)			
Once a colored drop of water was placed on the fabric surface, the diameter of the droplet was measured and found to be 7 mm. The droplet diameter was measured again after 30 and 60 seconds, but there was no change. This fabric is produced to be water-repellent.			
Sample No.2 (treated)			
Once a colored drop of water was placed on the fabric surface, the diameter of the droplet was measured and found to be 7 mm. The droplet diameter was measured again after 30 and 60 seconds, but there was no change. This fabric is treated to be water-repellent.			

Table 8 depicts that the contact angles increase after the treatment. The contact angle in samples Nos. 1 and 2 increased from 98 to 115 degrees after the treatment. The increase in water contact angles after the treatment shows that the treatment increased the roughness of the surface.

4.1.6 Effect of Treatment on Water Absorption

colored water was used in a dropper to place a droplet on the surface of a gray fabric; another droplet was placed on the same fabric after finishing. The diameter of the spot created by the water droplet was measured once the droplet was placed and after 30 seconds and 60 seconds to show the effect of treatment on water diffusion.

As a result, the difference between the treated and untreated samples is that the drop of water seems to be elliptical on the A surface of untreated fabric while, in the case of treated samples, it is circular. This is due to the surface tension of the fabric and the higher coefficient of friction.

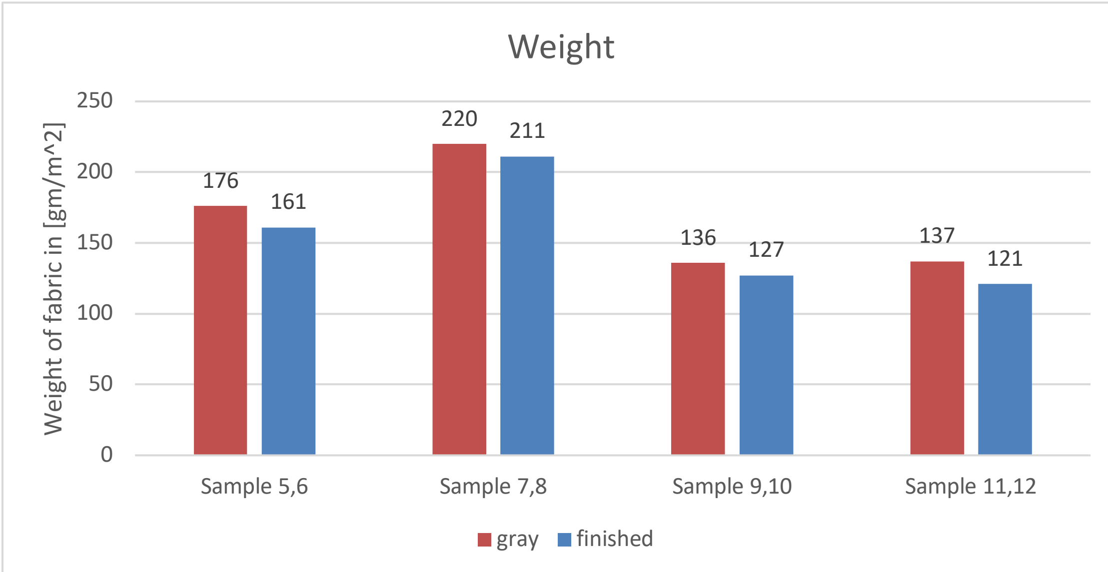


Fig. 6: Effect of finishing on fabric weight

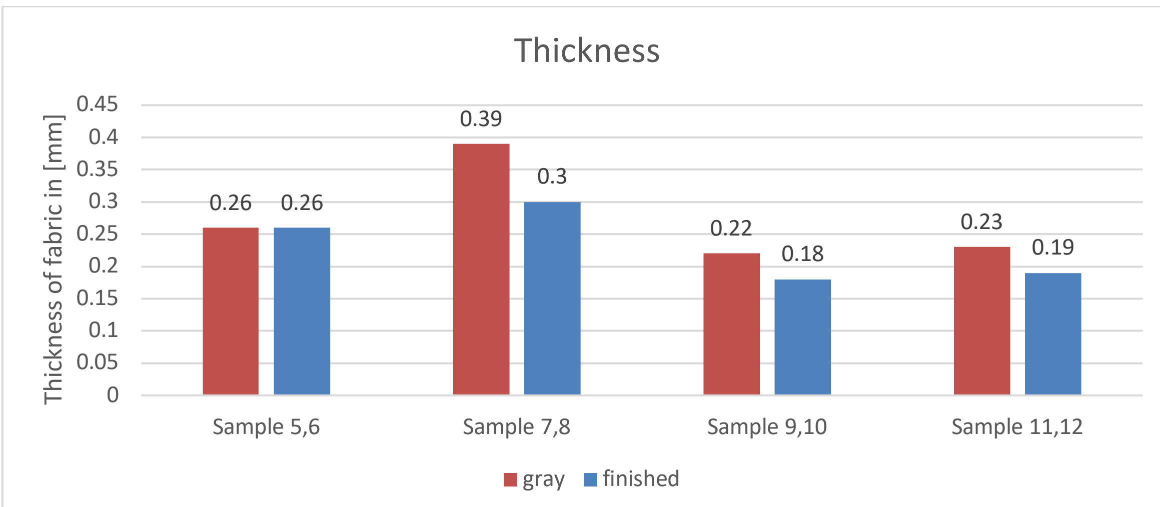


Fig. 7: Effect of finishing on fabric thickness

4.1.7 Effect of Treatment on fabric weight

From Figure 6, a Statistical Analysis of Fabric Weight Before and After Finishing could be made as follow:

The effect of finishing on fabric weight was evaluated by comparing the areal density (g/m²) of gray and finished fabrics for four sample groups (5–6, 7–8, 9–10, and 11–12).

Descriptive Statistics

• Mean weight of gray fabrics: 167.25 g/m²

• Mean weight of finished fabrics: 155.00 g/m²

This indicates an average reduction in fabric weight after finishing.

- **Minimum reduction:** 4.1% (Sample 7–8)
- **Maximum reduction:** 11.7% (Sample 11–12)
- **Average reduction:** ≈ **7.7%**

Interpretation: The results show that fabric finishing leads to a noticeable decrease in fabric weight for all samples. However, the extent of reduction varies among samples, which may be attributed to differences in fabric structure, yarn count, or finishing conditions. Overall, the finishing process caused an average weight loss of approximately 7–8%, confirming its significant effect on fabric areal density.

During the mechanical finishing, there will be loss in weight as well due to the removal of short ends and loose fibers on the surface of the fabric.

4.1.8 Effect of Treatment on Fabric Thickness

This is a Statistical Analysis of Fabric Thickness Before and After Finishing from figure (7):

The effect of finishing treatment on fabric thickness was evaluated by comparing the thickness values of gray and finished fabrics for four sample groups (5–6, 7–8, 9–10, and 11–12).

Descriptive Statistics

- Mean thickness of gray fabrics: 0.275 mm
- Mean thickness of finished fabrics: 0.233 mm

This indicates an overall decrease in fabric thickness after finishing.

The percentage reduction in thickness due to finishing was calculated using:

$$\text{Reduction (\%)} = \frac{T_{\text{gray}} - T_{\text{finished}}}{T_{\text{gray}}} \times 100$$

Table 10: Thickness Reduction Percentage

Sample No.	Gray (mm)	Finished (mm)	Reduction (%)
5–6	0.26	0.26	0%
7–8	0.39	0.30	30.0%
9–10	0.22	0.18	22.2%
11–12	0.23	0.19	21.0%

- Minimum reduction: 0% (Sample 5–6)
- Maximum reduction: 30% (Sample 7–8)
- Average reduction: ≈ 18.3%

Interpretation: The results demonstrate that fabric finishing generally reduces fabric thickness, although the degree of reduction varies among samples. Sample 5–6 showed no change in thickness, indicating that finishing had no noticeable effect on this fabric structure. In contrast, samples 7–8, 9–10, and 11–12 exhibited significant thickness reductions, with the highest decrease observed in sample 7–8 (30%). This variation may be attributed to differences in fabric construction, yarn packing density, and compressibility under finishing conditions.

Overall, the finishing process leads to an average thickness reduction of approximately 18%, confirming its notable influence on fabric compactness.

4.2 Impact of Treatments on Mechanical Properties

The mechanical properties of the fabric were significantly influenced by the application of paraffin wax. In particular, the tear strength increased notably in both warp and weft directions (as shown in Table 7), which may be attributed to the lubricating effect of the wax that facilitated smoother yarn slippage during tearing. This controlled slippage reduces stress concentration at the point of tear initiation, thereby enhancing the fabric's ability to resist propagation of tears.

At the same time, tensile strength also improved, indicating stronger inter-yarn cohesion and compactness induced by the treatment. These combined effects suggest that paraffin wax treatment provides dual mechanical benefits—enhanced tensile durability and improved resistance to tear propagation—which are valuable for technical or performance-based textile applications

4.2.1 Effects on Hydrophobicity and Durability

The effects of paraffin wax finishing treatment on hydrophobicity and durability were evaluated through a series of tests in this study. Initial water repellency was assessed by using contact angle measurements and water absorption tests, both of which indicated a significant increase in water resistance post-treatment [6].

4.2.2 Synergistic Effects of Combined Processes

The synergistic effects of the combination of paraffin wax finishing treatments with other processes show improved results in fabric properties [37]. Studies have proven that the combined paraffin wax impregnation and thermal modification significantly improve the rot resistance of materials and thus exhibit significant resistance [38]. Combined approaches also result in improved dimensional stability, as soaking and swelling in volume are reduced significantly. The use of a paraffin wax finish for woven fabric provides pronounced waterproof effects that create a barrier against penetrating water. Along with these functional enhancements, wax emulsions also support fabric robustness, sustainable production methods, and benefits that go far beyond the standards in conventional industries. Moreover, the synergistic effect in the form of durability, water resistance, softening, and stain resistance of the fabric are all enhanced [39]. In the same sense, the merge of paraffin wax finishing treatment with complimentary techniques strengthens specific strengths of a single fiber to strengthen the inter–yarn friction and improve structural change of the woven fabric.

4.2.3 Comparison with Untreated Fabrics

The study also discussed the direct comparison of paraffin wax-treated fabrics with the respective untreated fabrics. Both the fabrics, treated or untreated, were used to perform several tests to measure the transformed mechanical properties of the fabric, such as tensile strength, tear strength, contact angle, and water absorption. However, the results showed that the fabric coated with paraffin wax has a low surface energy film that not only repels water but also provides a smoother texture to the fabric surface. The untreated fabrics maintain their original surface characteristics, but those treated with paraffin wax have an increment in stiffness, which potentially changes the mechanical properties of the woven fabric. However, to improve the fiber characteristics, the wax coating processes were found to be effective in protecting the thread from abrasion, snapping, and fraying under pressure [40]. Overall, the paraffin wax treatments discussed in this study aimed to impart specific beneficial characteristics of treated fabric with the assessment of both mechanical and physical finishing properties, such as durability, tensile strength, and tear resistance of the woven fabric.

5. Conclusion

The application of paraffin wax treatment led to significant improvements in the mechanical and surface properties of woven fabrics. Specifically, tensile strength increased from 359.74 N to 434.17 N in the warp direction, while tear strength improved from 59.74 N to 110.01 N. The contact angle rose from 98° to 115°, indicating enhanced hydrophobicity. These results suggest that paraffin wax enhances inter-yarn friction and fabric cohesion while also imparting water-repellent properties.

However, studying has several limitations. The treatment was performed using commercial spray products rather than industrial emulsions, and no microscopic or surface roughness analysis was conducted to directly visualize structural changes. Additionally, durability was assessed only in the short term, with no extended washing or abrasion testing.

In conclusion, paraffin wax shows promise as a finishing agent for improving both mechanical and surface performance in textiles. Future work should include comparisons with bio-based and fluorine-free alternatives, long-term performance evaluations, and microscopic surface characterization to strengthen these findings.

6. Practical Recommendations and Future Research Direction

1. The study recommends that future researchers emphasize the optimization of paraffin wax application by methods such as dipping, spraying, or brushing the wax in the initial stages for uniform coating.
2. For the effective utilization of paraffin wax finishing treatments precise control over temperature is mandatory. It is recommended to record and maintain several temperatures to get the ideal results to balance the safety and effectiveness of the wax penetration in to fabric.
3. To optimize the additive concentration future researchers should explore other resources such as mineral oils or other similar substance to check their water repellency and finishing performances.
4. For the long-term durability and strength of the fabric extended washing and abrasion tests should be introduced to examine the paraffin wax longevity on the surface of the fabric.
5. The findings of the study also recommended that to adopt a sustainable and cost-effective technique future researchers should emphasize on the use of other wax and methods to address potential risks of paraffin wax such as high melting point.

References

[1] Negrete JDC, López VN. A sustainability overview of the supply chain management in the textile industry. International Journal of Trade Economics and Finance. 2020. 11(5):92–7. https://doi.org/10.18178/ijtef.2020.11.5.673.

[2] Grzymski F, Musiał M, Trapko T. Mechanical properties of fibre reinforced concrete with recycled fibres. Construction and Building Materials. 2018. 198:323–31. https://doi.org/10.1016/j.conbuildmat.2018.11.183

[3] Islam MdT, Jahan R, Jahan M, Howlader MdS, Islam R, Islam MdM, et al. Sustainable Textile Industry: An Overview. Non-Metallic Material Science. 2022. 4(2):15–32. https://doi.org/10.30564/nmms.v4i2.4707

[4] Singh V, Chauhan A, Tripathi A, Shukla K. An overview of Azo dyes degradation in textile industry effluents using microbes. Uttar Pradesh Journal of Zoology. 2023. 44(11):33–41. https://doi.org/10.56557/upjoz/2023/v44i113517

[5] Shim VPW, Lim CT, Foo KJ. Dynamic mechanical properties of fabric armour. International Journal of Impact Engineering. 2001. 25(1):1–15. https://doi.org/10.1016/s0734-743x(00)00038-5

[6] Abo-Shosha MH, El-Hilw ZH, Aly AA, Amr A, Nagdy ASIEl. Paraffin Wax Emulsion as water repellent for Cotton/Polyester blended fabric. Journal of Industrial Textiles. 2008. 37(4):315–25. https://doi.org/10.1177/1528083707083793

[7] Bajya M, Majumdar A, Butola BS. Criticality of inter-yarn friction in high-performance fabrics for the design of soft body armour. Composites Communications. 2021. 29:100984. https://doi.org/10.1016/j.coco.2021.100984

[8] Abu-Rous M, Dabolina I, Lapkovska E. Fabric physical properties and clothing comfort. IOP Conference Series Materials Science and Engineering. 2018. https://doi.org/10.1088/1757-899x/459/1/012028

[9] Gokarneshan N. Comfort Properties of Textiles: A review of some breakthroughs in recent research. Juniper Online Journal Material Science. 2019.5(3). https://doi.org/10.19080/jojms.2018.05.555662

[10] Yilma KT, Limeneh DY. Review on Moisture Management Finish: Mechanism and Evaluation. Journal of Natural Fibers. 2021.19(14):8628–36. https://doi.org/10.1080/15440478.2021.1966566

[11] Wang Y, Guo J, Li X, Krugl S, Jiao Y, Wang P. Towards yarn-to-yarn friction behavior in various

architectures during the manufacturing of engineering woven fabrics. Composites Part a Applied Science and Manufacturing. 2024.185:108363. https://doi.org/10.1016/j.compositesa.2024.108363

[12] Malik ZA, Malik MH, Hussain T, Arain FA. Development of models to predict tensile strength of cotton woven fabrics. Journal of Engineered Fibers and Fabrics. 2011. 6(4). https://doi.org/10.1177/155892501100600407

[13] Campos R, Bechtold T, Rohrer C. Fiber friction in Yarn—A fundamental property of fibers. Textile Research Journal. 2003. 73(8):721–6. https://doi.org/10.1177/004051750307300810

[14] Patti A. Green advances in wet finishing methods and nanoparticles for daily textiles. Macromolecular Rapid Communications. 2024. https://doi.org/10.1002/marc.202400636.

[15] Noor L, Humayoun UB, Sarwar N, Rasheed A, Yoon DH. Towards a greener future: utilization of Citrullus colocynthis seed oil emulsion as a sustainable functional soft finish for textiles application. Cellulose. 2023. https://doi.org/10.1007/s10570-023-05608-8.

[16] Gaur G, Sharma YK. Preparation and Properties of Wax Emulsions, Wax Dispersion and their applications in coatings. Journal Homepage. 2018. 6(5).

[17] Gulati R, Sharma S, Sharma RK. Antimicrobial textile: recent developments and functional perspective. Polymer Bulletin. 2022. 79(8):5747-71.

[18] Sarkara S, Kumara S, Singhb K, Mehraa D. Documentation of recent advancements in finishing methods and chemicals in the textile industry.

[19] Choudhury AKR. Green chemistry and the textile industry. Textile Progress. 2013. 45(1):3–143. https://doi.org/10.1080/00405167.2013.807601.

[20] Chen J, Chen W, Zhou H, Zhao B, Wang M, Sun W, et al. Fracture failure analysis and bias tearing strength criterion for a laminated fabric. Journal of Industrial Textiles. 2017. 47(7):1496–527. https://doi.org/10.1177/1528083717695839.

[21] Tensile strength testing with the Grab Test | CTL GmbH Bielefeld. CTL GmbH Bielefeld.

[22] Abtew MA. A comprehensive review of advancements, innovations and applications of 3D warp interlock fabrics and their composite materials. Composites Part B Engineering. 2024. 278. https://doi.org/10.1016/j.compositesb.2024.111395.

[23] Eltahan E. Structural parameters affecting tear strength of the fabrics tents. Alexandria Engineering Journal. 2017. 57(1):97–105. https://doi.org/10.1016/j.aej.2016.12.005.

[24] Fabric coating systems and methods. TVF.

[25] Sfameni S, Lawnick T, Rando G, Visco A, Textor T, Plutino MR. Super-Hydrophobicity of polyester fabrics driven by functional sustainable Fluorine-Free Silane-Based coatings. Gels. 2023. 9(2):109. https://doi.org/10.3390/gels9020109.

[26] Shim MH, Kim J, Park CH. The effects of surface energy and roughness on the hydrophobicity of woven fabrics. Textile Research Journal. 2014. 84(12):1268–78. https://doi.org/10.1177/0040517513495945).

[27] Rungruangkitkrai N, Phromphen P, Chartvivatpornchai N, Srisa A, Laorenza Y, Wongphan P, et al. Water repellent coating in textile, paper and bioplastic polymers: A Comprehensive review. Polymers. 2024.16(19):2790. https://doi.org/10.3390/polym16192790).

[28] Clothing Durability Report. Anthesis (UK) Ltd. 2015.

[29] Rajak D, Pagar D, Menezes P, Linul E. Fiber-Reinforced Polymer Composites: manufacturing, properties, and applications. Polymers. 2019. 11(10):1667. https://doi.org/10.3390/polym11101667.

[30] Perera YS, Muwanwella RMHW, Fernando PR, Fernando SK, Jayawardana TSS. Evolution of 3D weaving and 3D woven fabric structures. Fashion and Textiles. 2021.8(1). https://doi.org/10.1186/s40691-020-00240-7.

[31] Acme Mills. Characteristics of woven fabrics • ACME mills. Acme Mills. 2024.

[32] Palou A, Cruz J, Blanco M, Larraz R, Frontela J, Bengoechea CM, et al. Characterization of the composition of paraffin waxes on industrial applications. Energy & Fuels. 2014. 28(2):956–63. https://doi.org/10.1021/ef4021813. (36)

[33] El-Dalatony MM, Jeon BH, Salama ES, Eraky M, Kim WB, Wang J, et al. Occurrence and characterization of paraffin wax formed in developing wells and pipelines. Energies. 2019.12(6):967. https://doi.org/10.3390/en12060967 (37)

[34] Ilhan V. Industrial applications of paraffin wax. PetroNaft. 2023. (38)

[35] Ilhan V. Save Money: Make Your Own Paraffin Emulsion with Paraffin Wax. PetroNaft. 2024 (39).

[36] Islam R, Ghaffar S, Kong L, Biswas TK, Mahamudul HMD, Elias HM, et al. Highly efficient wear resistance and anti-wrinkle properties of cotton fabric finished by One-Step eco-friendly strategy. Fibers and Polymers. 2024. https://doi.org/10.1007/s12221-024-00699-x. (42)

[37] Gocek I. Synergistic effects of chemical finishing processes on comfort characteristics of micro-modal and lyocell knitted fabrics. Materials Testing. 2019.61(3):243–54. https://doi.org/10.3139/120.111312.

[38] Ilhan V. Paraffin wax for waterproofing. Petro Naft. 2023.

[39] Ilhan V. Wax emulsion for textile. Petro Naft. 2023.

[40] Hemptique. Waxed vs. Non-Waxed Thread: Definite Guide for Crafters.

[41] Ikumapayi O.M., Laseinde O.T., Ogedengbe T.S., Akinwumi A.O., Oluwafemi J.R., Akinlabi S.A., Akinlabi E.T. An Overview of Composites materials and their Machinability in Transport Industries. E3S Web of Conferences. 2023. 391 (1090). DOI: 10.1051/e3sconf/202339101090

[42] Leong W.Y., Leong Y.Z., Leong W.S. Green Building Initiatives in ASEAN Countries. 2023. Conference Proceedings - 2023 IEEE Asia Meeting on Environment and Electrical Engineering (EEE-AM 2023). DOI: 10.1109/EEE-AM58328.2023.10395261