Advanced Multidisciplinary Engineering Journal
AMEJ
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Journal Homepage
https://pub.scientificirg.com/index.php/AMEJ

The Dual Impact of Paraffin Wax and Finishing Treatments on Water Proofness and Strength of Raincoats

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ABSTRACT - This research investigates the dual impact of paraffin wax treatment and finishing processes on water repellency and mechanical strength of woven textiles. Paraffin wax treatment significantly increased fabric hydrophobicity, as indicated by enhanced water contact angles and reduced water absorption. Simultaneously, the treatment strengthened fabric tensile properties by increasing inter-yarn friction and compactness. However, tear resistance declined due to restricted yarn slippage. Finishing processes, while enhancing surface smoothness and weight uniformity, altered hydrophobicity by removing wax residues and improving water absorption in certain cases. The study reveals the complex trade-offs between hydrophobicity and strength in treated and finished fabrics, emphasizing the importance of selecting appropriate techniques to achieve balanced fabric performance. These insights contribute to the development of textiles with optimized water repellency and mechanical integrity for technical and apparel applications.

PAPER INFORMATION

HISTORY
Received: 14 June 2025
Revised: 26 September 2025
Accepted: 28 January 2026
Online: 6 February 2026

MSC
62K05
62K15

KEYWORDS
Textile Treatment, Fabric performance, Hydrophobicity, Water Proofness.

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1. Introduction

1.1 Background

In recent years, the textile industry has undergone a significant transformation with regard to producing in-demand, high-performance fabrics. It has encompassed the production of a multifaceted variation of fabrics and yarns that range from traditional clothing to high-end fashionable apparel. A recent trend toward the increased demand for performance fabrics in apparel and technical applications indicates the high consumer demand, seeking enhanced functionality and comfort in clothing and industrial products [1]. Therefore, Kaplan and Okur (2008) investigated the societal vendetta of subjective evaluation techniques, such as subjective wear trials and consumer perceptions, to understand the perseverance of consumers on comfortable clothing that not only provides a better fit but also makes an individual feel confident, yet comforted [1].

However, meeting the higher standards of consumer demands in accordance with sustaining fabric quality delivers at the expense of employing newer techniques and treatment methods that retain the cost-effective and eco-friendly protocols of fabric production [2, 3]. Furthermore, it has been observed that the textile industry has resurfaced as one of the highest water-consuming industries [4], which has brought forth a memento to endorse textile products that consume less water while exuding a high-functionality and fashionable aura. Thus, textile industries, in particular, have endorsed the production of hydrophobic and waterproof breathable fabrics while enhancing the fashionable aspect of the textile materials. The basic principle involved in designing breathable fabrics is the extent of treatment applied to the fabric surface to improve product shelf life without compromising the fabric's tensile strength. These treatments are largely employed on fabric surfaces to enhance hydrophobicity and repellency.

Thus, the textile industry has transitioned into producing highly breathable, wearable, and comfortable fabric that exudes a fashionable stance of the textile industry while replenishing and advancing the decade-old conventional fabric production methods [5]. However, the gradual shift to consuming water-repellent fabric with enhanced functionality and comfort has endorsed innovation in fiber technology and manufacturing processes, thus developing fabrics that showcase enhanced properties, for instance, moisture-wicking, breathability, UV protection, and durability [6]. Therefore, the growing interest of the textile industry toward transitioning into breathable fabric underscores the utilization of specific treatment methods that enhance fabric hydrophobicity and repellency. These treatments enhance fabric resistance to water penetration by creating a protective coating on the surface fibers. This contributes to a smoother fabric appearance and finishes with improved draping whilst adding the slightest hint of a softening effect [7]. In particular, it must be noted that the industry has largely endorsed the usage of cost-effective, non-carcinogenic, and eco-friendly methods and techniques to produce highly breathable yet water-repellent fabrics. These fabrics are significantly available in a large variety, specifically categorized as woven fabrics, microporous membrane and coating, hydrophilic membrane and coating, usage of retroreflective beads, smart breathable fabrics, and biomimetic-based fabrics [5]. However, the basic principles and mechanisms of water vapor transmission inherently depend on the type of breathable fabric used. Moreover, microporous and hydrophilic membrane and coating formulation and applications enclose significant diversity with regard to various fields of application. For instance, smart breathable and biomimetic-based fabrics, which are rather recent innovations, showcase enhanced potential toward wearability within domestic or industrial environments [5, 6]. Hence, this technology has been continuously evolving within industrial perspectives, where the production of cost-effective and environmentally friendly products is a significant concern. Therefore, such material formulations help improve the intrinsic and extrinsic fabric properties whilst controlling pore size and distribution to inhibit water absorption, damage, or contamination of fabric [8]. The implementation of such techniques on breathable fabrics improves monolithic film and coating materials for diverse applications. Hence, methods of membrane incorporation, coating techniques, fabric substrate, lining material, and garment construction undergo dynamic transformation to play a crucial role in designing, planning, and producing breathable garments [9]. Furthermore, technologies involving water-repellent coating on fabrics underscore their essential use in enhancing durability and sustainability. However, the use of sustainable technologies equally adheres to significant challenges that restrict the upgradation or innovation of conventional textile-producing methodologies [10]. Rungruangkitkrai et al. (2024), therefore, explored the advanced coating technologies to address such challenges, hence inherently focusing on the mechanisms, properties, and applications of producing high-performance fabrics with increased hydrophobicity. Hence, the water-repellent and resistant coatings on fabric help improve material performance and longevity. Moreover, traditional methods of textile production involve the use of highly carcinogenic materials and chemicals that impose a detrimental effect on the environment. Hence, the need to incorporate cost-effective and eco-friendly methods and chemical agents pertains to significant exploration at the expense of producing fabrics that consume less water and chemical agents [10]. Therefore, the current research explores the dual impact of paraffin wax and chemical/mechanical finishing treatment process on the mechanical strength, water repellency, durability, and performance of woven textiles across real-world applications.

1.2 Problem Statement

The existing literature presents significant hurdles and challenges in the textile industry with regard to optimizing the fabric’s water-repellent properties without compromising tensile or tear strength. Moreover, the existing research advocates the lack of a comprehensive understanding of the trade-offs between water repellency and mechanical strength when combining treatments and finishing processes. Few research studies comprehend or explore the dual effect of incorporating paraffin wax combined with finishing treatments to enhance water repellency and tensile strength without compromising fabric quality, comfort, and fashion [11]. Hence, the current research aims to gather inclusive insights by exploring the dual effect of paraffin wax and finishing treatment on woven textiles, aiming to add novel findings to fulfill the research gap. Moreover, the research aims to deduce findings that extrapolate the innovativeness of combining finishing treatments with paraffin wax to produce eco-friendly, cost-effective, and breathable textiles through environmentally friendly treatment methods and techniques.

1.3 Research Objectives

To assess the dual impact of paraffin wax treatment and finishing on the water repellency and mechanical strength of woven textiles. To explore the effect of each process on fabric durability and performance in real-world applications.

1.4 Research Significance

The research contributes by providing practical implications to textile manufacturers on combining paraffin wax with diverse finishing treatment methods and techniques to improve fabric performance across diverse applications (e.g., waterproof clothing and outdoor gear). Moreover, the research findings contribute to the development of textile products with optimized water repellency and mechanical integrity, thus enhancing fabric strength, comfort, durability, shelf-life, and avoidance of fabric degradation due to external or internal environmental settings.

2. LITERATURE REVIEW

2.1 Overview of Fabric Treatment Techniques

Fabric treatment techniques involve applying chemical or mechanical processes to modify fabric properties, enhancing its appearance, functionality, or performance by adding features like water/wrinkle/stain resistance, fire retardancy, softness, or anti-microbial properties. These are often achieved through dyeing, bleaching, finishing treatments, and specialized coatings, which largely depend on the desired outcome and essential customization of the fabric for the intended use. Numerous techniques and conventionally used fabric treatment methods aid in enhancing fabric properties, such as tensile strength, water repellency, UV absorbance, and durability, to increase textile product shelf life. Fabric treatment and finishing processes play a crucial role in enhancing functional properties, specifically with the addition of features that include water repellency and mechanical strength. This aids the fabric in enhancing its suitability for specific applications that improve its overall performance and durability across diverse environments. However, such characteristics are greatly achieved by modifying the fabric's surface characteristics through mechanical or chemical treatments that significantly impact fabric interaction with moisture and external forces, thus enhancing fabric usability and longevity [12]. The textile industries incorporate numerous fabric treatment methods that aid in enhancing the physical strength of the fabric. This largely involves the usage of paraffin wax, silicon coatings, and fluorocarbon treatments, alongside other methods that highlight the significance of incorporating innovative yet environmentally friendly methods to produce high water-repellent fabric with enhanced physical strength. For instance, paraffin wax, employed as a wax emulsion, has been extensively used across finishing treatment processes. The wax emulsion process involves the combination of emulsifiers, mixed wax, and water that assists in enhancing the internal strength of the fiber whilst increasing hydrophobicity [13, 14]. Paraffin wax is considered a highly emergent technique within textile finishing processes. It is usually used alone or in combination with other chemical coating processes that alleviate water repellency, appearance, appearance, comfort, durability, breathability, and fabric aesthetics [15, 16]. Hence, paraffin wax acts as a highly effective hydrophobic agent that significantly repels water. This aids the material to enhance its usage and value within textile processes, in instances where the production of moisture-resistant products is a significant concern. Furthermore, paraffin wax offers a protective barrier, offering cost-effective advantages that include high availability, cost-effectiveness, and easier application in comparison to numerous hydrophobic treatments [17].

2.2 Finishing Processes Used in the Textile Industry

The finishing processes used in the textile industry include various treatment methods that transform the strength of the fabric for the desired usage. These treatment methods ensure to meet the specific consumer needs when cost-effectiveness, eco-friendliness, and comfort are considered major concerns [18]. The finishing processes in the textile industry involve the utilization of mechanical, chemical, and thermal treatments, which significantly contribute to devising inherent fabric characteristics.

2.2. 1 Mechanical Finishing

Table 1 shows the mechanical finishing technique that enhances the properties, appearance, and performance of fabrics. These techniques alter the fabrics' internal structure without using chemical agents [18].

Table 1: Mechanical Finishing

Process	Treatment Description
Calendaring	This involves passing the fabric through heated rollers under pressure to ensure a smoother surface, improved luster, and reduced fabric thickness.
Embossing	Embossing involves pressing the design on the fabric through engraved rollers, which enhance fabric's texture and appearance.
Sanforizing	Sanforizing aids in pre-shrinking fabrics. The fabric is stretched and provided with adequate steam, followed by undergoing a relaxation process, which prevents shrinkage during the process of washing.
Brushing	The process of brushing involves the fabric surface fibers' mechanical raising to provide a softer and fuzzier texture. This process is highly common across flannels or other warm fabrics.
Shearing	Shearing involves the usage of rotating blades, over which the fabric is passed to cut surface fibers into a smoother fabric finish. This enhances fabric appearance and improves performance characteristics.
Raising	Raising involves lifting the fabric's surface fibers through teasel brushes or other mechanisms, which help create a softer and fuzzier texture commonly found in flannel.
Decatising	Decatising relaxes the fabric and reduces any residual stress. The fabric is steamed, followed by mechanically stretching to achieve a stable and uniform structure.
Crabbing	To enhance dimensional stability, the crabbing process is used to set the fabric's dimensions to enhance stability. The fabric passes through a series of rollers, which are subjected to heat and pressure.
Sueding or Sanding	Sueding, sanding, or peaching finishing involves abrading the fabric surface to create a suedelike texture, which enhances the fabric's softness and appearance.
Compacting	Compacting compresses the fabric to reduce thickness and improve stability. This enhances the fabric's appearance to enhance its suitability for certain applications.

2.2.2 Chemical Finishing

The chemical finishing process involves the application of chemical agents on the fabric surface to achieve the desired fabric strength [18]. **Table 2** shows the chemical finishing techniques that impact on the individual fabric properties.

Table 2: Chemical Finishing

Process	Treatment Description
Mercerization	Mercerization uses a caustic soda solution to improve the fibers' luster, strength, and affinity for dyes, thereby increasing the fabric's dimensional stability.
Scouring	The scouring process involves alkali washing of the fabric to remove contamination, waxes, and pectin. This process helps the fabric withstand further treatment and enhance absorbency.
Bleaching	Bleaching, a chemical process, uses oxidizing or reducing agents to lighten fabric color. This helps remove natural color impurities and likewise helps the fabric withstand the dyeing or printing process.
Dyeing	Fabrics undergo various dyeing processes to impart color. Dye types, for instance, reactive dyes, direct dyes, and vat dyes, are used to impart the desired fabric color.
Printing	The printing process involves a design or pattern on the fabric through colorants. Screen printing, rotary printing, and digital printing are types of printing processes that are employed across diverse fabric types.
Flame Retardant Finishes	Chemical treatments are applied to fabrics to provide flame retardancy. Flame-retardant finishes help reduce the flammability of the fabric and are highly essential in applications where fire resistance is essential.
Water Repellent and Waterproof Finishes	Chemical finishes like fluorocarbons are applied to the fabric to provide water repellency or waterproof properties. This is particularly useful in outerwear and outdoor textiles to protect against water.

Softeners	Softeners help enhance comfort and are applied to enhance softness and drape. However, silicone-based softeners are commonly used for this purpose.
Antimicrobial Finishes	Fabric is treated with antimicrobial agents to resist bacterial or fungal growth. This is used in textiles where hygiene is highly essential; healthcare and bedding.
UV Protection Finishes	To provide long-term durability, chemical finishes are applied to protect fabric against UV radiation. These finishes aid in reducing the susceptibility of the fabrics to fading and degradation caused by sunlight exposure.
Crease Resistance and Wrinkle-Free Finishes	Chemical treatments are applied to the fabric to provide resistance to creases and wrinkles. This is achieved by employing crosslinking agents that help stabilize fibers.
Stain-Resistant Finishes	To provide fabric maintenance, finishes that aid in repelling stains are applied to provide easiness to cleaning and maintenance.

2.2.3 Thermal Finishing

The process of thermal finishing involves heating properties that alter fabric properties by employing chemical applications on the surface of the fabric [18]. **Table 3** shows the description of the thermal finishing process.

Table 3: Thermal finishing

Process	Process Description
Heat Setting	Heat setting involves fabric exposure to elevated temperatures that stabilize dimensions and reduce shrinkage. This process prevents the fabric from further shrinking during subsequent washing.
Singeing	The singeing process involves passing the fabric over an open flame or heated plates to burn off protruding surface fibers. This enhances fabric smoothness, improves appearance, and reduces pilling.
Calendering	Calendering is also a thermal process, which involves passing the fabric through heated rollers under pressure to create a smoother and glossier fabric surface.
Heat Transfer Printing	Heat transfer printing involves the design transfer onto fabric using heat. Sublimation inks are often used, where the fabric is exposed to high temperatures. This allows the ink to permeate into the fibers.
Thermosetting	The thermosetting process involves fabric treatment with resin or a crosslinking agent, which is later subjected to heat. This heat treatment helps the resin/crosslinking agent to bond with fabric fibers, thus improving dimensional stability and crease resistance.
Heat-Resistant Finishes	To consider fabric resistance, each fabric is treated with finishes that provide resistance to heat. This is particularly important in applications where the fabric is exposed to high temperatures; protective clothing or industrial settings.
Thermal Bonding	Thermal bonding involves heat to adhere to fibers that create a non-woven fabric. This process is commonly used in producing non-woven fabrics, under applications, for instance, wipes and medical textiles.
Thermal Insulation	Fabrics are treated or combined with thermal insulating materials to trap and retain heat. This is often performed under fabrics used for winter clothing and bedding.
Flame Retardant Treatments	While chemical flame-retardant finishes are common, some flame-retardant treatments involve heat application. Consequently, the fabric is exposed to heat to activate flame-retardant properties.
Pre-Shrinking	Pre-shrinking involves high-temperature treatment to fabric to minimize shrinkage. This is essential to ensure that the garment maintains its shape and size after washing.
Curing of Coatings	In cases of fabric coatings, heat is often applied to cure or set coatings. This ensures fabric adherence to the coating.

2.3 Fabric Performance Metrics

2.3.1. Tensile Strength

The fabric's tensile strength is a highly significant mechanical property that ensures durability and comfort [19]. Woven fabrics are elastic in nature, and their mechanical properties are determined by fiber bundle combination, stacking sequences, yarn spacing, and sizes. The tensile strength provides an added characteristic, such as resistance, which protects the fabric from damage and high strain under external pressure or force. Furthermore, the difference between the entire fiber length (L0) and the length post-weaving (L1) is an essential parameter. Tensile strength is determined through the Grab test, where the fabric at both ends is pulled until the critical strength of the fiber is achieved. Moreover, the strip test, like the Grab test, is also performed, which focuses on the strength of the fabric strip to extend its length until the critical retention to withstand external force is achieved [21].

2.3.2. Tear Resistance

The fabric's surface coating affects tear strength. The laminate coating helps the fabric retain its tear strength. The material's ability to resist breakage until the composition's least count is essential to maintaining fiber integrity [22]. To enhance tear resistance, liquid or gaseous-based coatings are applied on the fabric surface; for instance, Polyurethane and Polyvinyl Chloride coatings provide a protective layer, ensuring lesser fiber disintegration [23]. The tongue tear method or the trapezoid tear method is used to examine the fabric's tear resistance or enhance tear resistance properties [22].

2.3.3 Hydrophobicity

Hydrophobicity is the fabric's ability to enhance water repellency. This property enhances surface water repellency and lowers the fabric's surface tension [24]. Modified sols with suitable hydrophobic substituents result in superhydrophobic and water-repellent films that are achieved in a single-step procedure [24]. Contact angle measurements, spray tests, and wetting time tests are used to assess fabric hydrophobicity and repellency. For instance, superhydrophobic fabric exhibits high contact angles (>150) with slight inclination [25]. Moreover, spray tests are employed to assess water hydrophobicity and fabric repellency to water. The wetting time test depends on the time taken by water droplets to enhance the penetration of water into fabrics. However, shorter wetting time indicates lower fabric hydrophobicity, which requires advanced usage of fabric surface coating [10].

2.3.4 Durability

Fabric durability refers to its shelf life and resistance to environmental degradation [26]. In particular, durability is categorized into physical and emotional durability. The fabric's physical durability is aimed at constructing and strategizing fiber reinforcement to generate a damage-resistant fabric despite multiple washings [27]. However, the fabric's emotional durability refers to the design, pattern, and color, which indicate the fabric's resistance to high-end quality, fashionability, and comfortability to individuals preferring enhanced fabric breathability with higher hydrophobic and water-repellent properties [26].

2.3.5 Fiber and Fabric Volume, Porosity, and Packing Density

Fiber volume, fabric volume, porosity, and packing density are measured to investigate the structural setting of the fabric fibers, particularly the amount of space occupied by the fibers within the fabric. This directly impacts important properties like air permeability, moisture absorption, insulation capacity, and overall strength, depending on the intended application of the fabric according to **Equations [1-4].** Therefore, after chemical, mechanical, or thermal treatment, the fabric is analyzed with regard to changes in the warp density, weft density, and yarn count. Moreover, fabric weight, thickness, sliding angle, contact angle, coefficient of friction, tensile and tear strength, and wetting behaviors are measured to assess treatment efficacy and the extent of resistance across diverse applications that require the use of heat and water-resistant fabrics.

Fiber volume was calculated according to the following **Equation 1**:

$$\boldsymbol{fiber\ volume\ (cm^3)} = \frac{\boldsymbol{fiber\ weight\ (gm)}}{\boldsymbol{fiber\ density\ (gm/cm^3)}} \quad \textbf{(1)}$$

Where the fiber density in the case of cotton fibers can be estimated as 1.54 gm/(cm)^3.

Fabric volume was calculated according to the following **Equation 2**:

$$\boldsymbol{fabric\ volume(cm^3)} = \boldsymbol{length} \times \boldsymbol{width} \times \boldsymbol{thickness} \quad \textbf{(2)}$$

Packing density was calculated according to the following **Equation 3**:

$$packing\ density\ (\%) = \frac{fiber\ volume}{fabric\ volume} \times 100 \quad \textbf{(3)}$$

Porosity was calculated according to the following **Equation 4**:

$$\text{porosity (\%)} = 1\text{-packing density} \quad \textbf{(4)}$$

Concerning the research objectives of the current study, these calculations are necessary to study the combined effect of paraffin and finishing treatments on the physical and mechanical properties of these fabrics.

2.3.6 Research Gaps and Opportunities

Per the existing literature, existing research studies lack the exploration of paraffin wax in combination with finishing treatments to assess the water-repellency and hydrophobicity of the fabric. Research studies do not fully comprehend the dual impact and the combined effect of paraffin wax and finishing treatments. Thus, the current research inherently advocates the exploration of paraffin wax treatment interaction with various finishing processes to achieve a balanced, high-performance, and highly hydrophobic fabric.

3. Proposed Methodology

3.1 Fabric Specifications

For the current study, five finished fabrics with similar weave structures were chosen. These fabrics were selected to examine the impact of paraffin wax treatment and finishing processes on water repellency and mechanical strength.

3.2 Justification for Fabric Selection

The chosen fabrics represent a diverse range of textile types commonly used in both industrial and consumer applications. The justification of the fabric selection is considered for several reasons, including diversity in fabric type, consistency in fabric structure, focusing on relevant properties, and enhancing sample relevancy with paraffin wax and finishing processes. Hence, the sample selection aimed to ensure the assessment of a controlled comparison between untreated and treated fabrics, isolates the variable of interest (water repellency and mechanical strength), and provides reliable data by controlling fabric structure and other external factors. Moreover, the selected fabrics differ in fiber content and structure (density and weight), allowing for a comprehensive analysis of paraffin wax treatment and finishing processes' interaction with different fabric types. This variation ensures that the findings apply to a wide range of textile materials. By selecting fabrics with varying properties, the study aims to provide insights into treatment and finishing processes that are optimized across a broader spectrum of textiles, making the results directly applicable to both the apparel and industrial textile sectors.

3.3 Fabric Sample Testing

Different testing apparatuses were used to analyze the samples. All the tests were carried out according to the protocols of ASTM.

3.4 Warp and Weft Density

A magnifying glass was used to obtain the warp and weft densities of the finished samples, post-treatment. Moreover, the number of ends and picks was also counted through the magnifying glass.

3.5 Fabric Weight

The fabric weight of all the samples was measured through the digital weighing scale shown in **Figure 1** after paraffin wax and finishing treatment.

Figure 1: Digital weighing scale

3.6 Fabric Thickness

Through the thickness tester shown in **Figure 2**, the treated samples were spread out on a stage above which the feeler disc was fastened to the end of a vertical rod. The rod may be moved up and down by means of an eccentric lever. Thickness values were read through the dial at the top of the instrument, after 30 seconds of loading.

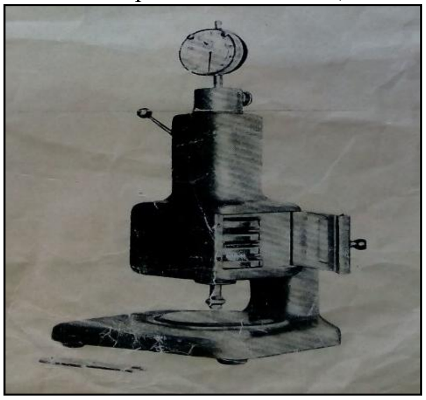


Figure 2: Thickness Tester

3.7 Sliding Angle

The sliding angle shown in **Figure 3** consists of two bars of wood, where the lower bar is fixed, and the upper bar is movable in an arc shape. The instrument provides a wooden protractor to move the upper bar of the instrument until the water drop slides at an angle. However, the angle may easily be measured using the attached protractor.

Figure 3: Sliding Angle Instrument

3.8 Coefficient of Friction

To determine the coefficient of friction, the treated samples were fixed to the upper bar, while a 500gms a dead weight was placed on the top of the samples. The upper bar was moved gradually till the weight began to move and slide down the specimen. Thus, the sliding angle was observed from the protractor and recorded.

3.9 Contact Angle

When the water droplet shown in **Figure 4** is dropped on the treated sample surface, the contact angle between the droplet and the surface is measured through the sliding angle instrument. However, the readings may not be precise by relative to each other to show the increase or decrease in water contact angle from one fabric to another. The diameter of the droplet used in measuring the contact angle of the samples was estimated as one centimeter.

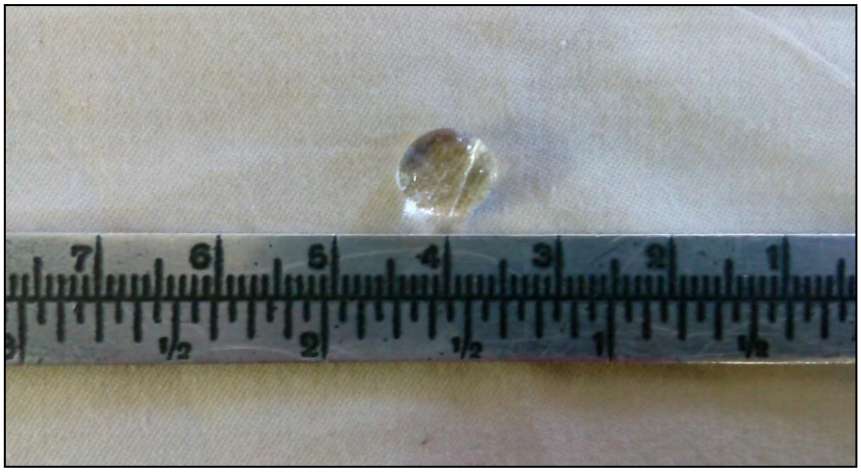


Figure 4:1cm water droplet

3.10 Tensile and Tear Strength

The Tensolab instrument shown in **Figure 5** was used to assess the tear and tensile strength of the treated samples. The instrument consists of: Adjustable feet, Lower clamp, Side panel for connections, Control panel, Upper clamp, Target and zero excursion, Protection panel, Load cell, Machine zero limit, Upper safety limit. The movement principle of the test is CRE (Constant Rate of Extension). To perform the test, the samples were fixed between the upper and lower clamps. The upper clamp begins to gradually move upward at a constant rate. However, the value of the applied force is recorded once the specimen breaks. Moreover, according to the standard ASTM D5035 for tensile strength test, the sample dimensions were kept at (20*3.5) cm, while the sample dimensions were kept at (20*7.5) cm for tear strength, according to the standard ASTM D5035.

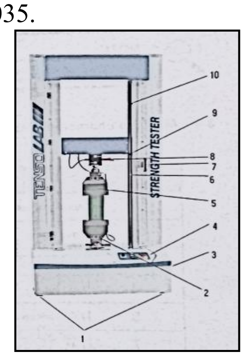


Figure 5: Tensolab Instrument

3.11 Treatment and Finishing Processes

In the current study, the selected samples underwent paraffin wax treatment to assess the fabric's resistance to water. Additionally, each fabric sample underwent specific finishing processes to enhance performance and aesthetic quality for real-world applications.

3.11.1 Paraffin Wax Treatment

The paraffin wax treatment was applied to the samples to enhance water repellency and evaluate its effect on mechanical properties. The following procedure was followed to prepare the paraffin wax, which outlines the key steps [16]. The paraffin wax was used in solid form and melted at 80°C to ensure uniformity during emulsion preparation. Specified weights of Paraffin Wax (9–18 g) along with Stearic Acid (3.75–11.25 g) were melted together in a 250 mL glass beaker in a thermostated water bath at 65–70 °C. To that mixture, 70 g of an aqueous solution of Triethanolamine (containing 5–20 g) at 65–70 °C was gradually added with stirring, using a strong homogenizer, within a period of 3 minutes. Stirring continues for an extra 3 minutes to obtain a homogeneous oil in the water mother emulsion. In the case of a metal salt-containing emulsion, the amount of Triethanolamine was dissolved in water to 50 g, and the emulsion was formed. Then, 20 g of an aqueous solution of the salt was added to the wax emulsion to form the metal salt-containing mother wax, which was diluted to achieve a 5%, 10%, and 15% (w/w) concentration.

These concentrations were selected based on preliminary trials to evaluate the optimal balance between water repellency and fabric strength of the fabric samples.

3.11.2 Application Methods

1. The sample fabrics were first cleaned to remove impurities that may affect paraffin wax application.
2. The paraffin wax solution was applied through the padding method, where the fabric samples were passed through a padding machine. The fabrics were then immersed in the paraffin wax and later squeezed to ensure even coverage.
3. Post-padding, the sample fabrics were rolled and allowed to rest for 10 minutes to ensure even wax penetration.
4. Curing Time: The wax-treated fabrics were cured in an oven at 80°C for 30 minutes to ensure that the paraffin wax is fully absorbed and set onto the fabric fibers.

3.11.3 Chemical Finishing

After paraffin wax treatment, chemical finishing was applied to the sample fabrics to modify the fabric's surface properties, improve uniformity, and evaluate interaction with wax treatment, as shown in **Table 4**.

Table 4: Chemical Finishing

Chemical Treatment	Parameter	Purpose
A softening agent (silicone-based) was applied to improve the fabric's hand feel and drape.	Temperature: 40°C Time: 15 minutes Chemical Agent: 5% silicone softener (by weight)	The softening agent imparts a smooth, supple texture to the cotton poplin, making it more comfortable for wear in clothing like shirts and dresses.
A water-repellent finish (fluorocarbon-based) was applied to enhance water resistance, which is especially important for outerwear and evening wear.	Temperature: 60°C Time: 10 minutes Chemical Agent: 2% fluorocarbon-based water-repellent agent	This chemical finishing improves the fabric's ability to resist water penetration while maintaining its shiny, crisp finish. It is ideal for garments such as rain jackets and formal outerwear.

3.11.4 Mechanical Finishing

After paraffin wax treatment and chemical treatment, the mechanical finishing process was applied on the sample fabrics to improve its texture, appearance, and performance, as shown in **Table 5**.

Table 5: Mechanical Finishing

Mechanical Treatment	Parameter	Purpose
Calendering, which involves passing the fabric through rollers to improve smoothness and surface gloss	Roller Temperature: 100°C Pressure: Medium pressure Time: 3 passes through the rollers	Calendering imparts a smooth, glossy finish to cotton poplin, making it more visually appealing and enhancing its softness and drapability.
Heat-setting, which helps to stabilize the fabric's shape and prevent shrinkage.	Temperature: 180°C Time: 5 minutes	Heat-setting the polyester taffeta ensures that the fabric retains its shape and prevents any distortion or shrinkage, which is important for garments like evening wear or upholstery.

4. Results and discussion

4.1. Fabric Weight and Thickness

Post paraffin wax, chemical, and mechanical finishing treatment processes, the sample fabric was tested to assess changes in the physical and mechanical properties, particularly warp density, weft density, fabric weight, and thickness, as shown in **Table 6** and **Figure 6.** They show the warp and weft yarn count of the treated samples. Samples 1 and 2 with yarn counts 16 and 15, respectively, are compared as their yarn counts are similar to each other. Samples 3 and 4 possess similar yarn count (36 metric). Thus, it is clear from **Figure 6** that sample 2 weighs 260 gm/m2, which is heavier than sample 1, weighing 178 gm/m2. This increase is due to the increase in warp density from 60 to 69. Moreover, the increase in warp density in sample 2 is due to the coarse structure of the yarn, as compared to sample 1. Therefore, post-treatment, the paraffin wax helped increase the warp density, thereby enhancing the yarn strength of the sample fabric. Although the difference in yarn count is small, the increase in weight is significant. Moreover, it is observed that sample 2 shows a smaller number of picks/cm and yet weighs heavier than sample 1. Therefore, the reduction in weft density possesses no significant influence on fabric weight in this case. In the case of samples 3 and 4, showing similar yarn count (36 metric), the increase in the number of ends and picks/cm helped increase the fabric weight from 87 to 138 gm/m2. Furthermore, the fabric thickness of all samples measured 0.30, except for sample 2, post-treatments. This may be due to a remarkable increase in weight.

Table 6: Warp Density, Weft Density, Fabric Weight, and Fabric Thickness, Post-treatment

Sample	ends/cm	picks/cm	Nm (warp)	Nm (weft)	Weight (gm/m2)	Thickness (mm)
1	60	60	16	16	178	0.30
2	69	48	30/2	30/2	260	0.33
3	64	54	36	36	87	0.30
4	100	72	36	36	138	0.30
5	103	97	80/2	80/2	131	0.30

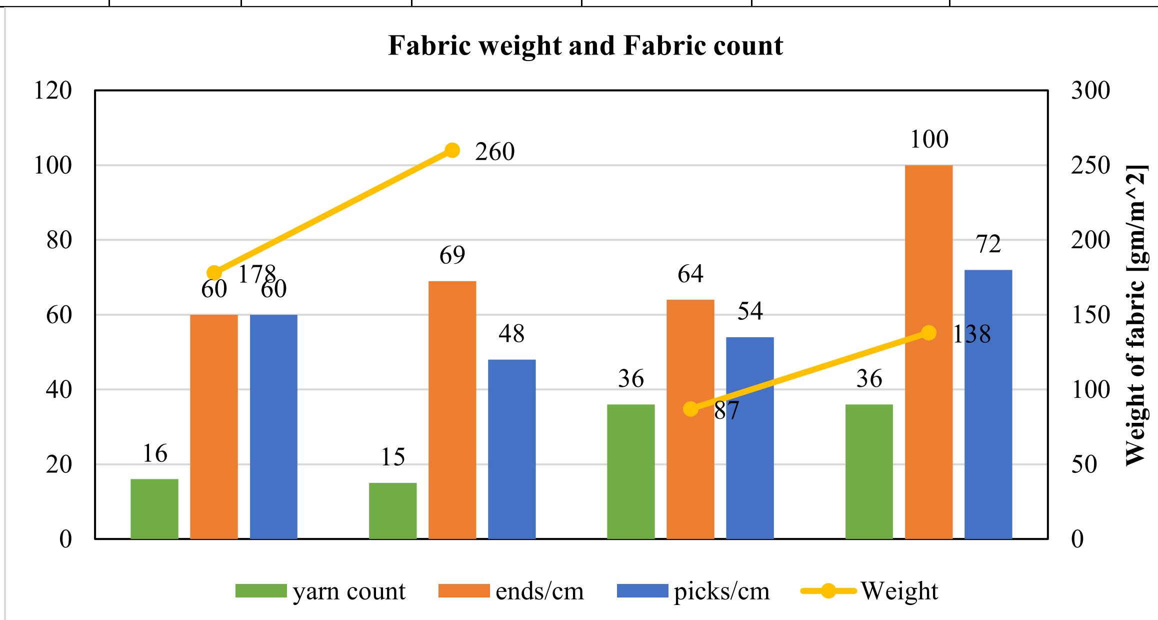


Figure 6: Weight of the Sample Fabrics, Post-treatment

4.2. Packing Density and Porosity

As shown in **Table 7** and **Figure 7**, samples 1 and 2 show yarn count as 16 and 15, respectively. Moreover, samples 3 and 4 show yarn count (36 metric). The increase in weight of samples from sample 1 (178 gm/m2) to sample 2 (260 gm/m2) has led to an increase in packing density from 39% to 51% and a reduction in porosity from 61% to 49%, post-treatment. Similar action has been observed for samples 3 and 4, as the increase in weight of samples from sample 3 (87 gm/m2) to sample 4 (138 gm/m2) has led to an increase in packing density from 19% to 30% and a reduction in porosity from 81% to 70%, post-treatment.

Table 7: Packing Density and Porosity, Post-treatment

Sample	Yarn count (Nm)	Weight (gm/m2)	Fiber Volume (cm3)	Fabric Volume (cm3)	Packing Density	Porosity
1	16	178	1.16	3	39%	61%
2	30/2	260	1.69	3.3	51%	49%
3	36	87	0.57	3	19%	81%

4	36	138	0.90	3	30%	70%
5	80/2	131	0.85	3	28%	72%

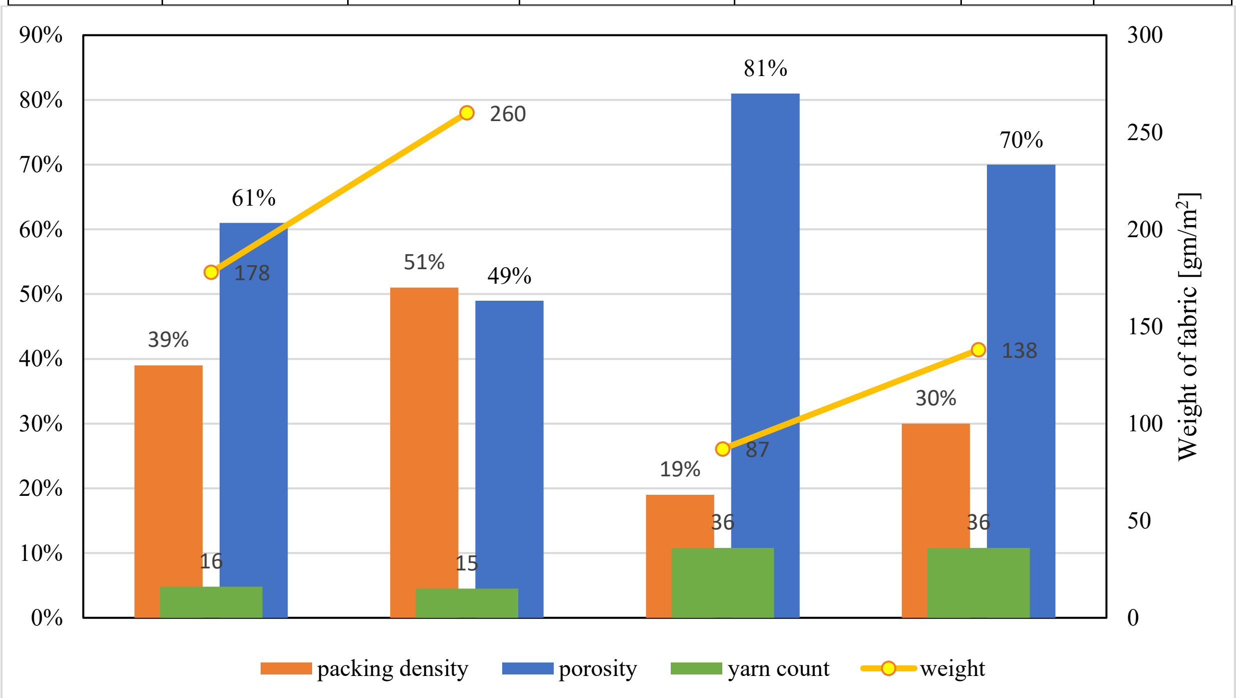


Figure 7: Packing Density and Porosity, Post-treatment

4.3. Tensile and Tear Strength

Table 8 shows the values of tensile and tear strength in relation to yarn count and fabric weight of the sample fabrics, post-treatment. According to **Figure 8**, the warp tensile strength and weft tensile strength of each sample are compared, and the warp strength is observed as higher than the weft tensile strength, which is due to the sizing of the warp thread and the enhanced strength of the thread, post-treatment. In the case of warp threads, the increase in weight of samples from sample 1 (178 gm/m2) to sample 2 (260 gm/m2) has led to an increase in tensile strength from 391.09 to 854.75 N with an increase of 118.56%. Also, the increase in weight of samples from sample 3 (87 gm/m2) to sample 4 (138 gm/m2) has led to an increase in tensile strength from 191.92 to 425.17 N with an increase of 121.54%. This is due to the increased strength of the fabric after the treatment, which caused the surface fibers of the fabric to enhance internal intactness, while further increasing the fabric's tensile strength, thus enduring enhanced external force.
According to **Figure 8**, in the case of weft threads, the increase in weight of samples from sample 1 (178 gm/m2) to sample 3 (260 gm/m2) has led to an increase in tensile strength from 288.76 to 490.58 N with an increase of 69.89%, post-treatment. Also, the increase in weight of samples from sample 3 (87 gm/m2) to sample 4 (138 gm/m2) has led to an increase in tensile strength from 162.64 to 239.38 N with an increase of 47.18%, post-treatment. The higher inter-yarn friction due to the increase in weight after employing paraffin wax and chemical and mechanical finishing treatments aided in increasing the friction between threads and compactness, which led to an increase in tensile strength. According to **Figure 9**, the warp and weft tensile strength of each sample are compared, and it is observed that the warp tensile strength is always higher than the weft tensile strength, which is due to the change in warp sizing, post-treatment. As shown in **Figure 9**, samples 1 and 2 with yarn counts of 16 and 15, respectively, are compared as their yarn counts impose similarity and closeness to each other. Samples 3 and 4, possessing similar yarn counts (36 metrics), are also compared and discussed. In the case of warp threads, the increase in weight of samples from sample 1 (178 gm/m2) to sample 2 (260 gm/m2) has led to an increase in tear strength from 35.12 to 73.12 N with an increase of 108.2%, post-treatment. Similarly, the increase in weight of samples from sample 3 (87 gm/m2) to sample 4 (138 gm/m2) has led to an increase in tear strength from 26.17 to 28.53 N with an increase of 9.02%, post-treatment. The higher inter-yarn friction due to the increase in weight after employing paraffin wax and chemical and mechanical

finishing treatments aided in increasing the friction between threads and compactness, which led to an increase in tear strength.

In the case of weft threads, the increase in weight of samples from sample 1 (178 gm/m2) to sample 2 (260 gm/m2) has led to an increase in tear strength from 32.95 to 59.53 N with an increase of 80.67%, post-treatment. However, a reduction in tear strength from 25.29 to 23.19 N with a reduction percentage of 8.30% from sample 3 to sample 4, with a lower reduction percentage, may be overlooked. Hence, it is noticeable that similar warp and weft density and with similar yarn count, causes an increase in the fabric weight, which leads to an increase in tear strength, after employing paraffin wax and chemical/mechanical finishing processes. However, other cases bear no significant influence of the treatment process. Hence, the higher inter-yarn friction due to the increase in weight aims to increase friction between threads, causing compactness, which further leads to enhanced resistance of the fabric toward tear strength.

Table 8: Tensile and Tear Strength, Post-treatment

Sample	Yarn count (Nm)	Weight (gm/m2)	Tensile Strength (N)		Tear Strength (N)	
			warp	weft	warp	weft
1	16	178	391.09	288.76	35.12	32.95
2	30/2	260	854.75	490.58	73.12	59.53
3	36	87	191.92	162.64	26.17	25.29
4	36	138	425.17	239.38	28.53	23.19
5	80/2	131	433.7	267.13	19.34	23.57

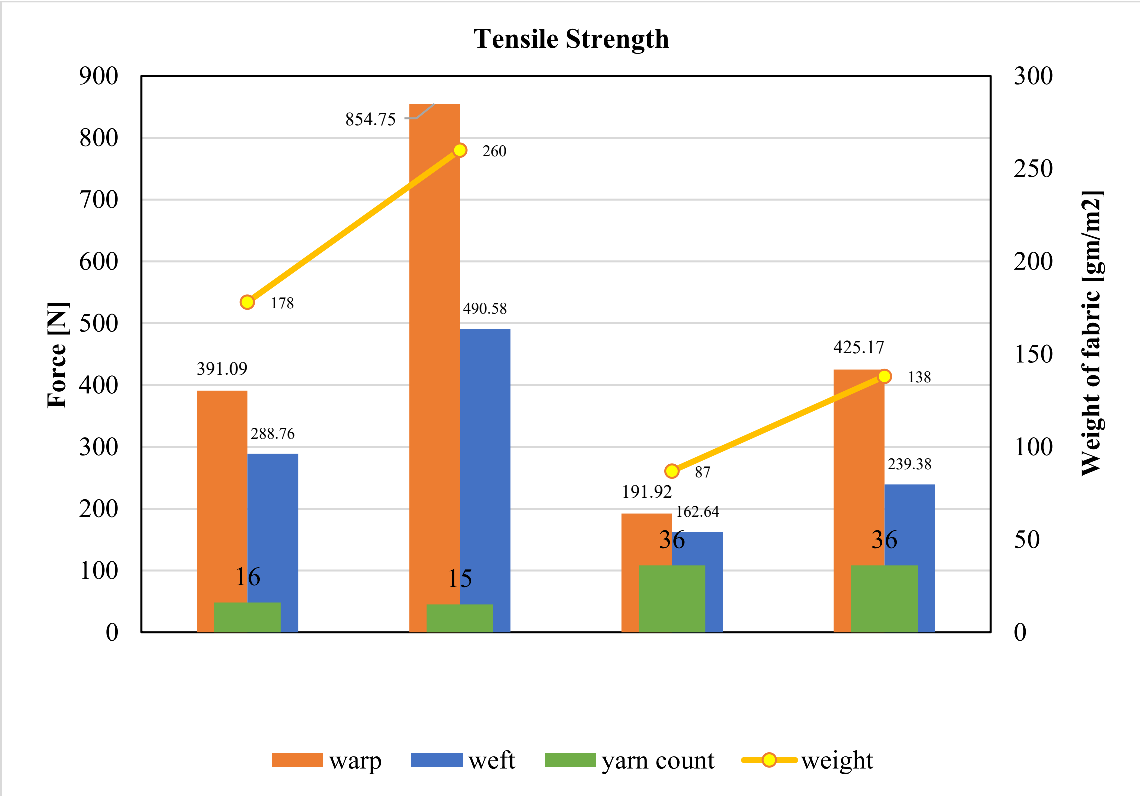


Figure 8: Tensile Strength, Post-treatment

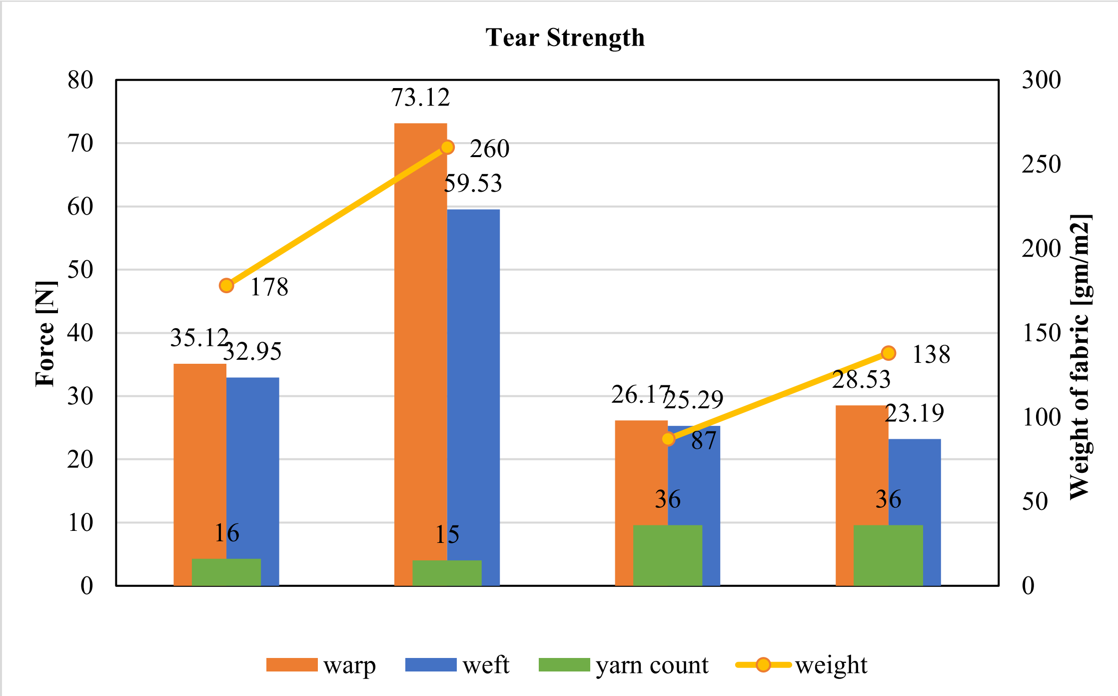


Figure 9: Tear Strength, post-treatment

4.4. Coefficient of Friction and Contact Angle

The usage of the sliding angle instrument, alongside a 500-gram dead weight, is paramount to measure the sliding angle once the dead weight begins to slide off the fabric. The friction between the fabric surface and the metal dead weight is expressed by the sliding angle from which the fabric's coefficient of friction may be calculated. As shown in **Figure10 and Table 9**, samples 1 and 2 with yarn counts 16 and 15, respectively, are compared as their counts are similar to each other. Samples 3 and 4 possess similar yarn count (36 metric), which are equally compared and discussed. Hence, it is clear that the reduction in the coefficient of friction of samples from sample 1 (μ=0.6) to sample 2 (μ=0.49) with 25% reduction has led to an increase in contact angle from 100% to 108%, post-paraffin wax and chemical/mechanical finishing treatment. A similar process has been observed between samples 3 and 4, as the reduction in coefficient of friction of samples from sample 3 (μ=0.58) to sample 4 (μ=0.53) has led to an increase in contact angle from 110% to 125%, post-paraffin wax and chemical/mechanical finishing treatment.

Table 9: Sliding Angle, Coefficient of Friction, and Contact Angle, Post-treatment

Sample	Sliding Angle (°)	C.O. F	Contact Angle (°)
1	31	0.60	100
2	26	0.49	108
3	30	0.58	110
4	28	0.53	125
5	32	0.63	103

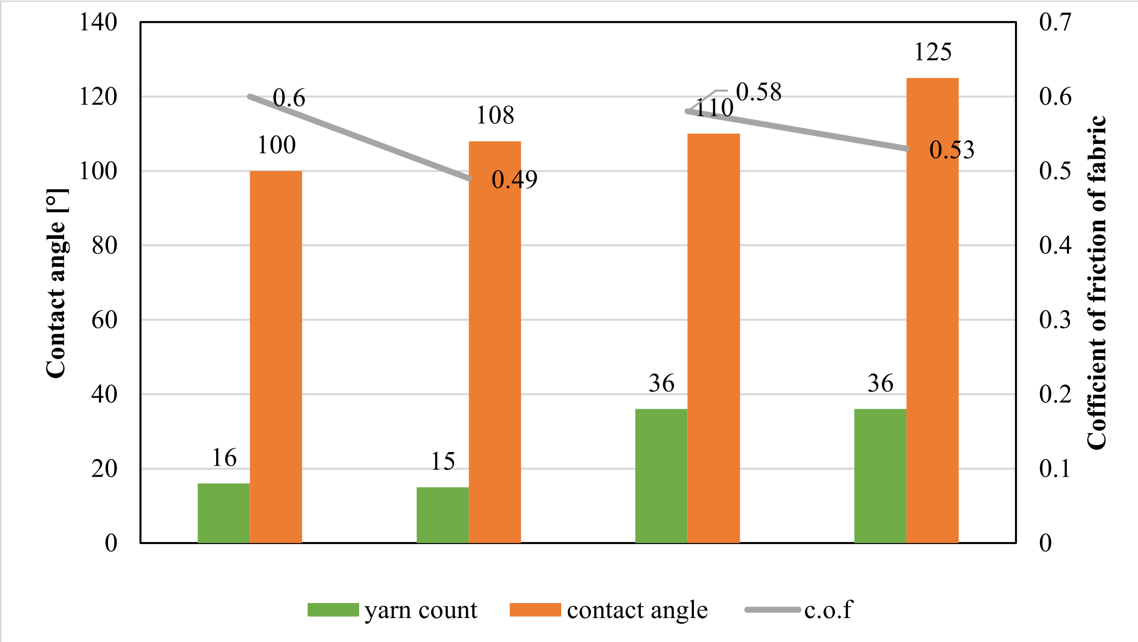
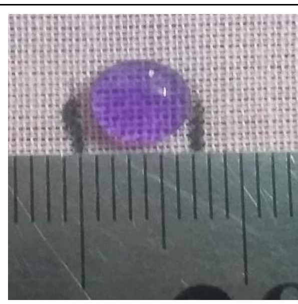
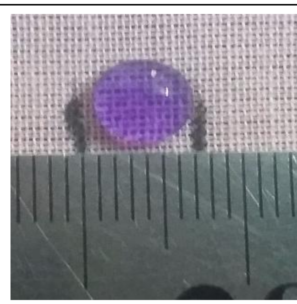
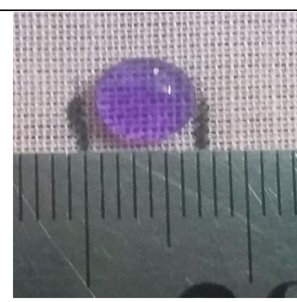


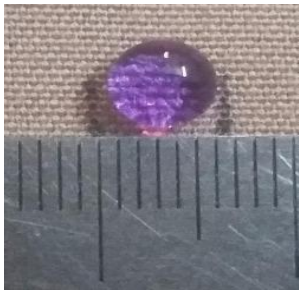
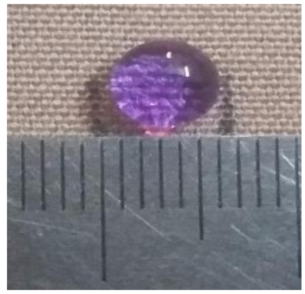
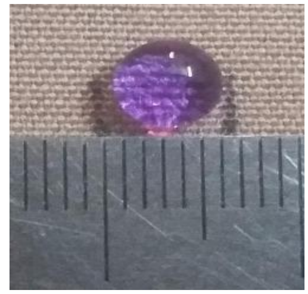
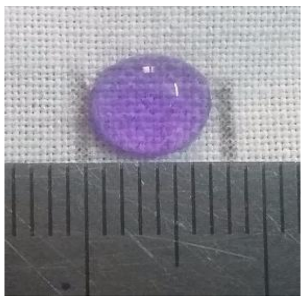
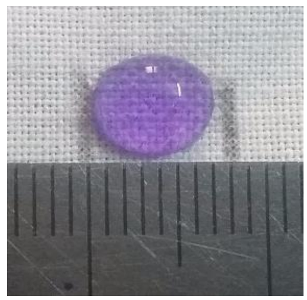
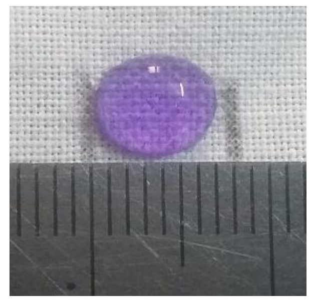
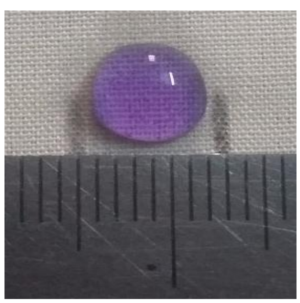
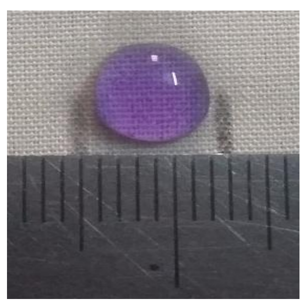
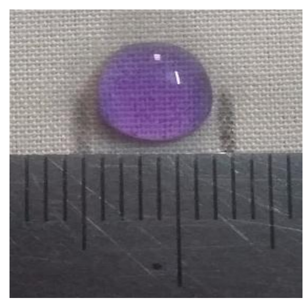
Figure 10: Coefficient of Friction and Contact Angle of the Sample Fabrics, Post-treatment

4.5. Water Absorption

A colored water droplet was placed on the fabric, post-treatment. The diameter of the spot created by the water droplet was measured after 30 and 60 seconds, once the droplet was placed, to assess the effect of paraffin wax and chemical/mechanical finishing processes on the finished fabric. Theoretically, the fabric finishing must increase its affinity toward water; however, it was observed as rather contrary through the water absorption test. Hence, it is clear from **Table 10** that the paraffin wax, combined with the chemical/mechanical finishing processes, increased the fabric's hydrophobicity toward water, thus enhancing water repellency and mechanical strength. Hence, the treatment enhanced surface smoothness, fabric tightness, and consequently improved water repellency and physical/mechanical strength.

Table 10: Water Absorption Test on the Sample Fabrics, Post-treatment

Time	0 secs	30 secs	60 secs
Sample 1			
A colored water droplet was placed on the fabric surface, and the diameter of the droplet was measured and found to be 7 mm. The droplet diameter was measured again after 30 and 60 seconds; however, no apparent change was observed post-treatment.			

<table>
<tr><td>Sample 2</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">A colored water droplet was placed on the fabric surface, and the diameter of the droplet was measured and found to be 6 mm. The droplet diameter was measured again after 30 and 60 seconds; however, no apparent change was observed post-treatment.</td></tr>
<tr><td>Sample 3</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">A colored water droplet was placed on the fabric surface, and the diameter of the droplet was measured and found to be 8 mm. The droplet diameter was measured again after 30 and 60 seconds; however, no apparent change was observed post-treatment.</td></tr>
<tr><td>Sample 4</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">A colored water droplet was placed on the fabric surface, and the diameter of the droplet was measured and found to be 8 mm. The droplet diameter was measured again after 30 and 60 seconds; however, no apparent change was observed post-treatment.</td></tr>
</table>

4.6. Impact of Treatments on Mechanical Properties

Per the findings of the current study, the combined effect of the paraffin wax, followed by chemical and mechanical finishing processes on the sample fabrics, showcased enhanced mechanical properties, precisely tensile strength and tear resistance. While testing the tear and tensile strength, post-paraffin wax and chemical/mechanical treatment, the sample fabrics showed enhanced tear and tensile strength, as the paraffin wax coating strengthened the internal structure of the fibers. Hence, the combined or dual effect of paraffin wax, alongside chemical and mechanical finishing processes, is essential to increase the strength of the fabric while enhancing fabric resistance to breakage. In accordance with the current research findings, the hydrophobicity test on the sample fabrics was accompanied by a water absorption test. The results revealed high hydrophobicity of the fabric samples, making them highly desirable under conditions where enhanced resistance to water is majorly concerned. Per the assessments of the current research, the synergistic effects of the paraffin wax and the chemical and mechanical finishing processes aided in enhancing the overall fabric performance. However, potential synergies combining different fabric treatment methods with paraffin wax, may aid in enhancing water repellency, alongside acknowledging the dual nature of the paraffin wax and finishing treatments on textiles.

5. Conclusions

The research involves the implementation of paraffin wax, followed by mechanical and chemical treatment processes on cotton and polyester. The treatment combination is implemented to enhance the mechanical properties and water-repellency rate of the fabric. Hence, the research inherently advocates the dual nature of the paraffin wax and the finishing processes to enhance fabric durability under conditions where higher water repellency is primarily considered. The combined treatments significantly influenced fabric performance, precisely hydrophobicity, water absorbency, water contact angle measurements, and evaluation after multiple washes. The findings showed that polyester, in comparison to cotton, showed better tensile strength and resistance to tears. Moreover, polyester fabric showed higher contact angle measurements and better water absorbency rates than cotton. In addition, the results indicate the high-end retention of the treated polyester against evaluations after multiple washes. However, the research imposes high significance toward providing valuable findings to the existing literature, thus contributing to improving fabric durability and providing better resistance under applications that require high-stress-resistant fabrics. Thus, the current research identifies the need for potential synergies where the usage of combined processes enhances water repellency without significantly compromising the mechanical strength of the fabric.

6. Recommendations

Industries, alongside research scholars, should optimize textile treatments and finishing processes for specific applications (e.g., outdoor gear, industrial fabrics, or fashion). The research recommends future research studies to select treatment combinations that differ from those selected in the current research. This may leverage the researchers to meet performance requirements without sacrificing durability. Future research studies should explore alternative treatments, different finishing techniques, or more advanced testing methods. In addition, future research studies should devise potential exploration of the long-term performance of treated fabrics under varying environmental conditions (e.g., prolonged exposure to water, UV radiation, or abrasion).

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