international DESIGN JOURNAL
Print ISSN 2090-9632
Online ISSN 2090-9640

Enhancing the Softness of Bamboo Fabric as a Sustainable Material through Silicon-Based Modifications

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Abstract

One of the biggest advantages of bamboo is that holds the title of the fastest-growing woody plant on Earth, surpassing even the fastest-growing tree species. Certain bamboo varieties are capable of growing an impressive 1 meter per day. This material is an excellent replacement for synthetic fibers derived from petroleum-based compounds, which are becoming scarce. It also offers a viable alternative to natural fibers, whether plant-based or animal-derived, that is experiencing production limitations. The world is increasingly adopting eco-friendly materials, with bamboo standing out as the fastest-growing woody plant on Earth. Widely cultivated in Asia, bamboo serves as a versatile, renewable resource for various functional and decorative products. As awareness of environmental issues and personal health rises, eco-conscious fabric production is in demand. Bamboo fabric, known for its softness, drapability, and pesticide-free cultivation, is a sustainable option. This study involved treating bamboo fabrics with silicone compounds to assess their impact on various mechanical properties, including durability, moisture absorption, stiffness, weight loss, and overall performance.

Keywords

Bamboo, sustain, softeners compounds, PDMS

Paper received January 22, 2025, Accepted March 18, 2025, Published on line May 1, 2025

Introduction

As global resource demands increase and the severe impacts of our ongoing dependence on fossil fuels become increasingly evident, there is a growing emphasis on sustainable, nature-based solutions to address the complex environmental challenges our planet faces. 1-2

The world is continually exploring and adopting innovative materials, with an increasing preference for eco-friendly products. One standout option among these sustainable materials is bamboo, known for being the fastest-growing woody plant on Earth3. This renewable resource is extensively cultivated across Asia and serves as the foundation for a wide variety of functional and decorative items. 4

This paper examines the properties and ecological benefits of bamboo fiber. Regenerated bamboo fibers, recognized for their high cellulose content, have gained significant popularity in the market, positioning bamboo as a fashionable and durable eco-friendly material for construction. Due to its exceptional properties, bamboo fiber is widely used to produce yarns and textiles5. These fibers are incorporated into a diverse range of products, including apparel such as underwear, activewear, t-shirts, and socks, as well as personal care items like sanitary pads, and are utilized in various sectors such as healthcare, military, industry, home decor, and furnishings.1-6

Nowadays, attitudes toward bamboo are gradually improving, although progress has been somewhat slow7. As awareness grows, the demand for bamboo is rising, primarily due to its rapid growth and the diverse range of valuable products it can produce. The variety of species available also allows for bamboo cultivation in regions far beyond its native habitat x. Some bamboo species are known to sequester significant amounts of carbon, in addition to their numerous benefits8. Bamboo fibers are expected to be extremely important in the future9. They are already utilized in various products, including textiles.

Bamboo history:

Bamboo belongs to the subfamily Bambusoideae and the family Gramineae (Poaceae). While the exact origins of bamboo in the evolutionary history of plants remain unclear, it is believed that bamboo likely emerged around 30 to 40 million years ago.10

Bamboo is considered one of the most valuable forest resources and has significant socioeconomic, cultural, and ecological importance that has lasted for millennia11. In Ethiopia, for instance,

CITATION Shaimaa Kamel (2025), Enhancing the Softness of Bamboo Fabric as a Sustainable Material through Silicon-Based Modifications, International Design Journal, Vol. 15 No. 3, (May 2025) pp 489-499

indigenous bamboo has been used in a wide variety of traditional applications, including constructing homes, building fences, crafting household items, making utensils, feeding animals, and harvesting edible shoots for human consumption12. The cultivation and use of bamboo have been essential to human societies throughout history.

There are currently 1,575 species of bamboo spread across roughly 90 genera around the world. Bamboo covers an estimated 37 million hectares, making up about 1% of the planet's forested land. Its annual production surpasses 20 million tons, generating around $60 billion for the global economy.13-14

Bamboo grows in diverse climatic and ecological zones, thriving in tropical, subtropical, temperate, and even frigid regions, with its distribution spanning from about 50°N to 47°S latitude. It can also be found at varying altitudes, from sea level to as high as 4,500 meters above sea level.

Ecological Benefits of Using Bamboo for Textiles and Clothing:

- **Rapid Growth:** Bamboo, the largest member of the grass family, can grow up to 35 meters tall and is the fastest-growing woody plant, thriving in diverse climates, making it a sustainable and versatile resource. it is The fastest-growing plant on Earth.15
- **Sustainable Harvesting:** Bamboo regenerates naturally after being cut, much like grass, and can be continuously harvested without harming the surrounding environment.
- **Climate Benefits:** Bamboo reduces carbon dioxide and produces 35% more oxygen than equivalent tree stands, helping to mitigate global warming.
- **Water Efficiency:** Bamboo requires only 500 liters of water to produce 1kg of fiber, compared to cotton, which needs up to 20,000 liters. Bamboo does not require irrigation. (Bamboo requires only natural rainfall, while cotton needs 15,000 liters of water to produce just 1 kg)
- **Biodegradable:** Bamboo fiber is fully biodegradable and can be composted, offering an environmentally friendly disposal option.
- **Health Benefits**: Known as "Air Vitamin" in Chinese academia, bamboo fiber releases anions that activate body cells, purify blood, aid recovery, calm the nervous system, and improve allergic conditions.
- **Eco friendly plant**: Bamboo cultivation requires no pesticides or chemical fertilizers, making it an inherently organic material

Bamboo preparations:

Bamboo can be transformed into textile fibers through two primary processes. The first is a mechanical process, where the bamboo's woody parts are crushed, and natural enzymes are used to break down the bamboo's cell walls into a soft pulp. This allows for the mechanical extraction of natural fibers, which are then spun into yarn. While this eco-friendly method is sustainable, it is more labor-intensive and expensive compared to the chemical process.

The second process is chemical manufacturing, which produces regenerated cellulose fibers resembling rayon.

Bamboo fiber is created by treating the bamboo's leaves and woody sections with powerful chemical solvents like sodium hydroxide and carbon disulfide, followed by a multi-stage bleaching process. While this production method is fast, it is not considered environmentally sustainable.

Stages of Bamboo Fiber Production

Preparation: Bamboo leaves and the soft inner pith from the bamboo trunk are extracted and crushed.

Steeping: The crushed bamboo cellulose is soaked in a 15-20% sodium hydroxide solution at 20ºC to 25ºC for 1-3 hours, forming alkali cellulose.

Pressing: The alkali cellulose is mechanically pressed to remove excess sodium hydroxide solution.

Shredding: The alkali cellulose is shredded to increase surface area for easier processing.

Aging: The shredded alkali cellulose is dried for 24 hours, where it partially oxidizes and degrades to lower molecular weights, ensuring proper viscosities for spinning.

Xanthation: Carbon disulfide is added to the alkali cellulose, causing it to gel and form cellulose sodium xanthate. The remaining carbon disulfide is removed by evaporation.

Dissolving: A diluted sodium hydroxide solution dissolves the cellulose sodium xanthate, creating a viscous solution with 5% sodium hydroxide and 7-15% bamboo cellulose.

Spinning: After ripening, filtering, and degassing, the viscose bamboo cellulose is extruded through spinneret nozzles into a container of diluted sulfuric acid. This process hardens the cellulose sodium xanthate, converting it back into bamboo fiber threads. These threads are then spun into yarns, which can be woven into regenerated bamboo textile products.

Applications of Bamboo Fiber in the Fashion Industry

Intimate Clothes: This category encompasses products like sweaters, swimsuits, mats, blankets, and towels. These items are prized for their softness, unique sheen, excellent moisture absorption, and vibrant color options.

Non-Woven Fabric: Crafted from pure bamboo pulp, this fabric shares characteristics with viscose fibers. However, bamboo's antibacterial properties make it particularly valuable in hygiene products, including sanitary napkins, masks, mattresses, and food packaging.

Sanitary Materials: This category includes products such as bandages, masks, surgical wear, and nursing garments. Bamboo fiber's natural antibacterial and sterilizing qualities make it ideal for sanitary applications, such as sanitary towels, gauze masks, absorbent pads, and food packaging.

Bathroom series: The bamboo bathroom collection features towels and bathrobes known for their soft, luxurious feel and superior moisture-wicking abilities. Bamboo fiber is also used in socks and various medical products due to its excellent absorption properties. Thanks to its natural antibacterial qualities16-17, bamboo helps prevent the growth of bacteria18, reducing the risk of unpleasant odors.

Chemical properties:

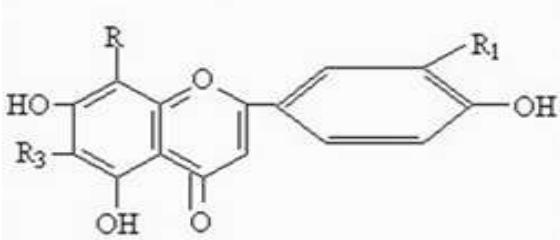
Bamboo is mainly made up of cellulose, hemicellulose, and lignin, with trace amounts of other components like aqueous extracts, pectin, and inorganic substances. The exact chemical makeup of bamboo can vary depending on the species. In bamboo timber, the key components are cellulose (60%–70%), pentosans (20%–25%), hemicelluloses (20%–30%), and lignin (20%–30%). It also contains small amounts of resins, tannins, waxes, and inorganic salts. Notably, bamboo has lower cellulose content than cotton. Hemicellulose is an amorphous material with a low degree of polymerization.19-20

Bamboo's structure consists of long fibers and microfibers that are highly absorbent, leading them to swell when exposed to moisture. Lignin, a complex macromolecular compound from the aromatic series, is present within the intercellular layers and tiny fibers of bamboo. The fiber's color is influenced by the lignin content.17

Chemically, bamboo shares similarities with hardwoods in its proximate composition but contains higher levels of alkaline extract, ash, and silica. The carbohydrate content in bamboo plays a key role in its durability and lifespan. Additionally, the plant's resistance to mold, fungal infections, and borer attacks is strongly tied to its chemical makeup.

As a natural nanocomposite, bamboo possesses multinodal and functional gradient structures at both macro and micro levels. The intermodal cells in bamboo grow in a pale, end-to-end alignment.

Chemical constituents	Percentage
Cellulose	73.83
Hemicellulose	12.49
Lignin	10.15
Aqueous Extract	3.16
Pectin	0.37



Chemical Structure

Textile Modification

The use of chemical additives to modify the properties of both natural and synthetic fibers has a long history. Fabric softeners, often used in washing machines, reduce the roughness of textiles during air drying, serving as after-treatment aids. Wrinkle releasers, applied directly to fabrics, also offer significant benefits.21

Softeners, a key group of textile additives, reduce friction between fibers, creating a softer surface and providing lubrication. These treatments are essential in the finishing process, ensuring textiles are functional, easier to handle, and more pleasant to use. Textile softeners typically work through the oriented adsorption of active substances onto the fiber surface. Common organic softeners include hydrophobic fatty residues, typically with hydrocarbon chain lengths ranging from C16 to C18. These substances are systematically applied to the fiber surface, allowing the individual fibers to slide more freely against each other. As a result, the treated textile feels noticeably softer compared to untreated fabrics.22-23

The main benefits of using softeners are as follows:

- Enhancing the product's aesthetic qualities, making it feel soft, smooth, fluffy, and more flexible to the touch.
- Improving various functional properties, including antistatic effects, moisture absorption, and flexibility, sewing ease, wipeability, and reducing pilling.
- For synthetic fiber products, softeners can help modify the texture to mimic the feel of natural

fibers.

Softeners are not only applied as a final finishing treatment but also play a key role in processes such as scratching, sanforization, sewing, and yarn rewinding to achieve the desired effects.

Textile softeners should possess the following essential qualities:24-25-26

a. Ease of application (e.g., maintaining solution stability after dilution).
b. Compatibility and miscibility with other additives used in finishing baths.
c. Simplicity in the finishing process.
d. Effective softening performance.
e. Skin-friendly attributes—should not release harmful gases or cause allergic or irritating reactions during treatment.
f. No tendency to cause yellowing or discoloration, ensuring resistance to sunlight and dye stability.
g. No alteration of the fabric’s color during treatment.
h. Low foam production and resistance to shear forces
i. No residue left on padding machine rollers.
j. Strong affinity for agents used in batch treatments applied to the fiber.
k. Ability to be applied via spray.
l. Non-toxic and anticorrosive properties.
m. Easy biodegradability.
n. No special transportation or storage restrictions related to flash points.
o. Stability during high-temperature treatments in dyeing and finishing processes (e.g., non-volatile and unaffected by water vapor).
p. Stability during storage, biodegradable, and in line with environmental protection standards
q. Excellent wash resistance
r. Cost-effective pricing.

The textile industry uses a variety of softeners, such as cationic, anionic, non-ionic, paraffin and polyethylene-based, ethoxylated non-ionic, and silicone-based formulations.27-28-29

Softeners are chemically similar to surfactants, as both share similar structures. While most surfactants can provide varying levels of softness to textiles, not all commercial softeners are considered detergents. Typically, textile softeners are formulated as water emulsions containing 15% to 25% active ingredients.30

In addition to traditional compounds derived from aliphatic fatty hydrocarbons, a newer class of softeners has emerged as silicones. These modern softeners have become increasingly popular over the past twenty years. Silicones, in particular, are frequently incorporated into other softener formulations. Additionally, silicone compounds are often used as modifiers to improve textile properties.

Silicone compounds:

Silicon does not exist in its pure form; rather, it is found as sand ($SiO2$) or within metal silicates. To obtain silicon metal, it is extracted from sand ($SiO2$) through an oxidation process. Once extracted, silicones are synthesized from silicon metal through a three-step procedure.31

Silicones are a type of polymer with an inorganic backbone made of alternating silicon and oxygen atoms, paired with organic side groups. This distinctive structure grants silicones their exceptional properties, making them highly suitable for a wide range of uses, including textile coatings.32

Silicones are among the most adaptable polymers available, significantly enhancing fabric value by modifying the material's texture to meet consumer expectations. Derived from the abundant resource of sand, silicones are organometallic polymers characterized by a framework of alternating silicon and oxygen atoms (known as siloxane bonds), with organic groups, typically methyl groups, attached to the silicon. Polydimethylsiloxanes are the most common type used in commercial applications 31-33

Thanks to their unique inorganic-organic structure and the flexibility of their silicon bonds, silicones possess exceptional properties, including thermal stability, low-temperature flow, and minimal viscosity variation with temperature, high compressibility, low surface tension, hydrophobicity, excellent electrical conductivity, and low flammability. A distinctive advantage of silicones is their efficiency at very low concentrations, where small amounts suffice to impart the desired characteristics. This enhances the cost-effectiveness of textile processes while minimizing environmental impact.

Silicone materials exhibit a high resistance to biodegradation by microorganisms, but they can undergo natural chemical breakdown through processes like catalyzed hydrolysis and oxidation. This degradation leads to the formation of siloxanols and silanols. Being ecologically inert, silicones do not interfere with aerobic or anaerobic bacteria, making them harmless to the biological processes involved in wastewater treatment. As an eco-friendly chemical solution, silicones provide an excellent option to meet a wide range of customer needs.

General structure of silicone softener

Silicone Modifications and Resulting Properties

- Amino Group: Offers excellent softness, durability, and high exhaustibility.

- Hydrophilic Group: Provides water-absorbing qualities.
- Methyl Group: Delivers water-repellent and anti-static effects.
- Hydrogen Group: Enhances water-repellent and soil-resistant capabilities.
- Other Organomodifications: Improves drapability and wrinkle recovery properties.

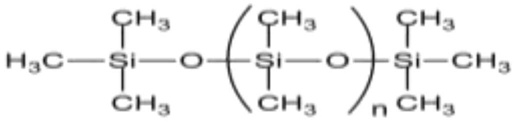
Silicone compounds properties

a. **Elasticity:** Silicone elastomers are highly flexible, with some grades demonstrating an elongation at break of over 1,000%. This remarkable elasticity makes them ideal for use as coatings on textiles that require high stretchability, such as ELASTAN®, without affecting the fabric's performance.
b. **Hydrophobic** and Waterproof Properties: Silicone rubber is naturally water-repellent. When water is placed on a smooth silicone surface, it forms a contact angle of around 130°, indicating that silicone-coated textiles resist water penetration. Even thin coatings can enable fabrics to withstand water pressures exceeding 10 meters.
c. **Temperature Resistance**: Silicone materials are known for their outstanding flexibility and resistance to extreme temperatures. Silicone elastomers typically perform well within a temperature range of -45 °C to +180 °C. Special grades can endure up to 250 °C and briefly withstand exposure to temperatures as high as 300 °C.
d. **Flame Resistance:** Silicones are naturally flame-retardant, with an autoignition temperature around 430 °C. When exposed to fire, silicone materials convert into silicon dioxide, which forms a white ash. The gases released during this process are non-toxic and non-corrosive. By adding specific additives, silicone-coated textiles can be made to meet rigorous fire safety standards.
e. **Chemical Resistance:** Silicone elastomers are highly resistant to a range of organic chemicals, as well as dilute acids and bases in aqueous solutions. While exposure to solvents like ketones, esters, and hydrocarbons may cause swelling, they do not degrade the silicone's chemical structure.
f. **UV and Weathering Resistance:** Silicones offer outstanding resistance to UV radiation. Their hydrophobic nature and strong chemical resistance make them highly durable against weathering, Specialty silicone formulations can endure 1.5 million cycles without any deterioration in surface properties. Moreover, silicones absorb short-wave UV light, providing added protection to textile fibers from UV-induced damage.
g. **Electrical Properties:** Silicones are electrically insulating materials with a typical dielectric strength of greater than 23 kV/mm; it also provides specialized electrically conductive and antistatic silicones.
h. **Wash Resistance:** Silicones form strong chemical bonds with a wide range of substrates, which makes silicone-coated textiles particularly durable. This durability is evidenced by their outstanding wash resistance.34-35
i. **Anti-Slip Properties:** Soft silicone coatings provide anti-slip properties to textiles, enhancing their wash resistance and skin compatibility.
j. **Food Contact :** When processed correctly, many silicones comply with Recommendation XV from the German Federal Institute for Risk Assessment (BfR) and the requirements of the Food and Drug Administration (FDA) 21 CFR § 175.300 concerning resinous and polymeric coatings. Please note that each individual silicone formulation must be approved for use in food industry applications.
k. **Biocompatibility:** Silicones are biologically inert, meaning that biological organisms do not recognize silicone as a foreign material. This property makes silicone elastomers ideal for medical applications.
l. **Sterilization Resistance:** Silicone elastomers are highly resistant to standard sterilization processes, including steam, Ethylene Oxide (ETO), and gamma radiation, making them a preferred material for medical applications.
m. **Translucency and Color Customization:** Silicone elastomers are inherently translucent, offering the ability to be easily colored to almost any shade, providing greater design versatility for products.

Silicone softeners play an essential role in the final stages of fabric processing. After pretreatment, dyeing, and fixing, fabrics often become stiff and rough, this can be off-putting to consumers. By applying silicone softeners, the fabrics are transformed into soft, smooth textiles, greatly enhancing their comfort and appeal.

Silicones are widely utilized across various stages of textile production36, from fiber and yarn manufacturing to the final fabric finishing. Their distinctive chemical properties offer a range of benefits that enhance the overall quality of textiles37. Different silicone technologies are employed in multiple applications throughout the textile industry.

In this study, PDMS was chosen because of its common application in coating fibers and fabrics. It acts as effective oil or finishing agent, providing a remarkably low friction coefficient and an exceptionally smooth texture to the fibers and their final products.38-39 it is known that Low molecular weight PDMS (<1000 Da) is found in personal and household care products, while high molecular weight PDMS is used as an antifoam and ointment in industrial and domestic settings.40



Chemical structure PDMS (polydimethylsiloxane)

Materials and Methods

Bamboo fabrics

Knit fabric (bamboo) had single jersey (S/J) structure was supplied from national research center, (NRC).

Chemicals

All chemicals used in this research were of analytical grade purchased from local supplier. Sodium hydroxide (NaOH) , and non-ionic wetting agent; Triton X – 100 was utilized for the fabric scouring process in order to remove any oils , wastes any foreign substance. A silicon-based softener, poly dimethyl siloxane amine (PDSA), was applied to improve the smoothness and quality of the Bamboo fabric.

Preparatory process

Scouring

Cotton fabrics were subjected to treatment with a 4.0% sodium hydroxide solution and a wetting agent at a 1:50 (w/v) liquor ratio for 90 minutes at boiling temperature. Following the treatment, the fabrics were thoroughly rinsed with hot and cold water before being air-dried at room temperature.

PDSA Treatment

The scoured bamboo fabric was treated with silicone softener (PDSA) at varying concentrations (10, 30, and 50 g/L) to improve its softness. The process involved immersing the alkali-treated fabric in a silicone softener solution for 15 minutes, with constant stirring. Following the treatment, the fabric was dried in an oven at 100 °C to remove excess moisture, and then cured at 150 °C to enhance adhesion and ensure better penetration of the softener into the fibers.41

The samples were labeled according to the specific treatments applied: SB refers to scoured bamboo without any treatment, S1 corresponds to scoured bamboo treated with 10 g/L silicone softener, S2 represents scoured bamboo treated with 30 g/L silicone softener, and S3 indicates scoured bamboo treated with 50 g/L silicone softener.

Testing and analysis

Each sample was assessed under standard atmospheric conditions of 25±2°C and 65% relative humidity, following a 24-hour conditioning period. All fabric specimens were subjected to a series of tests, both prior to and following treatment, to evaluate the outcomes in line with the specified testing protocols outlined below:

Weight change evaluation

The evaluation of weight change was determined using the following formula:

$$\text{Weight change percentage} = \frac{Wb - Wp}{Wb} \times 100$$

Where, Wb= Fabric weight before treatment and Wp= Fabric weight post-treatment

Spray rating test (ISO 4920-2012 (E)

This test method assesses the water repellency of fabric. The Spray Test is employed to measure the fabric's resistance to surface wetting when exposed to mild water impact. The fabric’s surface is evaluated visually. It is a popular method due to its simplicity, speed, and cost-effectiveness as a screening test. Spray rating tests were carried out using a Spray Tester at the National Research Centre (NRC) in Egypt.

Bursting strength test

The bursting strength of the fabric was tested using the ASTM D3786 standard method.

Abrasion resistance test

Abrasion resistance was measured by the weight loss rate using the ASTM D4966 method.

Stiffness test (Flexural rigidity)

To evaluate the fabric stiffness in the warp and weft directions, the flexural rigidity (gm.cm) is calculated using the formula $G = wc^3$, where w is the fabric weight per unit area, and c is half of the fabric's bending length. The flexural rigidity of the fabric was measured using a stiffness tester, following the procedure in ASTM D 1388-08 according to the standard test method JIS-L1018, using Universal Wear Tester, Toyo seiki-Japan.42-43

PDSA Characterization of pre- and post-treatment samples (FTIR)

Fourier transform infrared (FTIR) spectroscopy was used to identify the functional groups in both untreated and treated samples. Pellets were separately prepared from the treated samples, and FTIR spectra were obtained using the FTIR 6300 instrument from Jasco Inc., Japan. The spectra were collected in the range of 4000 cm^{-1} to 500 cm^{-1}, with 32 scans averaged at a resolution of 4 cm^{-1}.

Results and discussion

The weight change

Data presented below showed that the weight of fabric increases in all treated samples at all concentrations which mean that finishing increasing the treated fabric weight. This result may be due to the formation of a soften film on the fabric surface.23

The results suggest a positive correlation between the solution concentration and the weight change of the fabric, indicating that higher concentrations result in a more significant effect on the fabric's weight.

Sample	The weight change (%)
S 1	4.27
S 2	7.35
S3	11.33

Spray test

All treated fabrics exhibit varying levels of water repellency, as demonstrated in the subsequent data. This water repellency is attributed to methyl groups arranged and attached to the fiber surface through silicone bonds. The fabric also has the potential for crosslinking with Si-OH or Si-OR terminal species44

Sample	The spray rating scale	
SB	0	Complete wetting of the entire face of the specimen
S 1	2	Partial wetting of the specimen face beyond the spray points
S 2	2	Partial wetting of the specimen face beyond the spray points
S3	3	Wetting of specimen face at spray points

Mechanical attributes:

The mechanical strength of a fiber is essential for its suitability in the apparel industry, especially when enhancing the quality of fabrics.31 The results detailing the bursting strength and the behavior of finished fabric samples are presented below.

Sample	the bursting strength
SB	5.00 KGM
S 1	5.00 KGM
S 2	4.90 KGM
S3	4.40 KGM

The previous results show a marginal difference between treated and untreated samples. The bursting strength of the fabric samples varies based on treatment conditions:

SB represents the baseline strength. Sample S1 shows similar results to the baseline. Sample S2, with a bursting strength of 4.90 KGM, exhibits a minimal decrease, indicating little impact from the treatment. In contrast, Sample S3 shows a decrease to 4.40 KGM. Among all samples, the finished fabrics have the lowest bursting strength, which may be attributed to their surface characteristics. The use of PDSA significantly reduces fiber friction, resulting in a softer handfeel for both the fiber and the fabric.45

It is evident that the treatment decreases fabric strength, which is reasonable given the increase in concentration. The reduction in bursting strength of the fabric can be attributed to the influence of the cellulosic fiber during the cross-linking process.

Abrasion Resistance:

The purpose of this test is to evaluate the material's resistance to abrasion and to predict its durability in real-world applications. The abrasion resistance of the treated fabrics was determined by measuring the weight decrease rate. A lower weight decrease rate indicates better abrasion resistance of the fabric, while a higher rate suggests poorer resistance.

The results, which are presented below, show the effects of different concentrations of PDMS on abrasion resistance. It can be observed that the abrasion resistance of the treated fabrics improved with increasing concentrations of PDMS. This enhancement may be attributed to the formation of a film on the fabric after the crosslinking of the silicone compound.

Samples SB and S1 exhibited poor abrasion resistance, whereas samples S2 and S3 demonstrated better resistance. This improvement is likely due to the increased silicon concentration, which led to a higher density in the fabric, enhanced by the formed film 46.

Sample	Abrasion resistance test
SB	2
S1	2
S2	3
S3	3

Flexural Rigidity:

The stiffness decreased for all types of treated samples. The fabric stiffness is decreased by increasing of treatment conc. As the Finishing concentration increased the fabric Flexural Rigidity is decreased which means less stiffness.

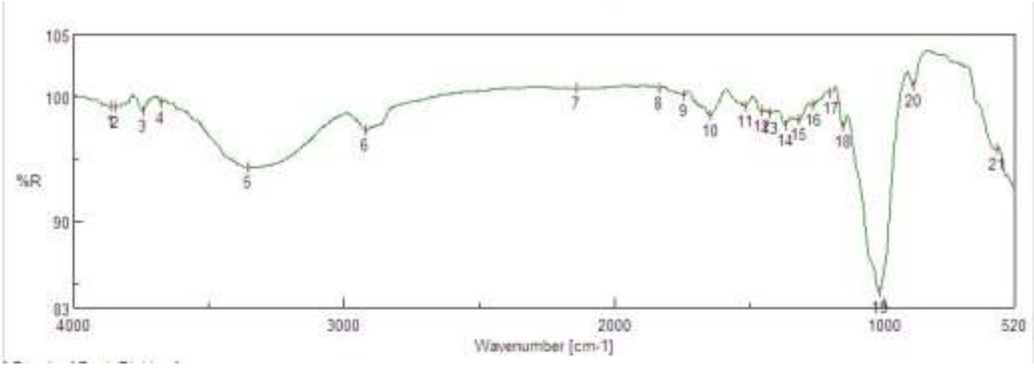
The effect of using PDSA and its concentration on the flexural rigidity of fabrics was determined and the results presented below. The results of flexural rigidity results in that the rate of stiffness was lower at using high finishing agent concentration.44

Sample	Flexural Rigidity
SB	356
S 1	276
S 2	178
S3	98

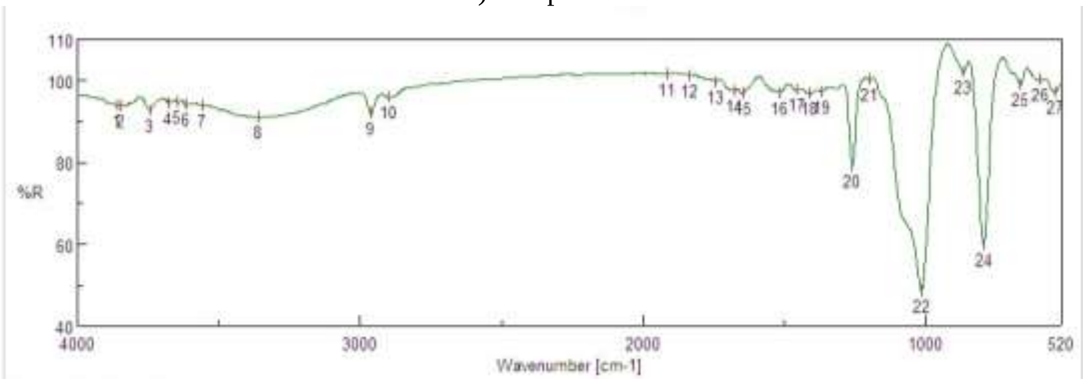
The flexural rigidity of the fabric samples varies notably depending on the applied treatments. Sample SB serves as the reference point. Compared to this baseline, Sample S1 exhibits a reduction of 80 units, indicating a moderate decrease in rigidity—softening the fabric slightly while maintaining some stiffness. Sample S2 experiences a more pronounced reduction of 178 units, suggesting a significant softening effect. Sample S3 undergoes the greatest decrease, with a reduction of 258 units, making it the least rigid among the samples.

In summary, the treatments progressively softened the fabric, with Sample S3 showing the most substantial reduction in rigidity, followed by Sample S2 and Sample S1.

The FTIR characterization of PDSA



a) Sample SB



b) Sample S3

Fig.(1) : FTIR spectrum bamboo fabric; a) untreated bamboo (SB), b) treated bamboo with PDSA 50 g/l (S3

FT-IR spectroscopy offers a simple method for detecting silicon on fabric. Silicones exhibit absorption bands at 1260, 1100-1000, and 770 cm^{-1}, allowing differentiation down to 1 percent 47-48

From figure (1), Diagram (a), it is observed that:

- Peaks at 1835 and 1743 cm^{-1} are strong indicators of the presence of carboxymethyl functional groups (COO^-).
- Broad bands in the range of 3862-3679 cm^{-1} suggest O-H stretching. The spectrum also shows peaks near 3355 cm^{-1} that may correspond to the hydroxyl group (O-H stretch), while peaks around 2921 cm^{-1} are characteristic of alkane C-H stretching.
- Peaks in the 1600-1500 cm^{-1} range (specifically at 1644 and 1515 cm^{-1}) suggest C=C stretching, which is commonly found in aromatic rings.
- Additionally, the peaks at 1835 and 1743 cm^{-1} indicate the presence of carbonyl functional groups (C=O), suggesting that esters or carboxyl groups are present.

From figure (1) Diagram (b):

- A clear marker for amine groups is the N–H stretch observed at a peak of 3361 cm^{-1}, indicating amine functionalization.
- The peaks at 2962 cm^{-1} and 2900 cm^{-1} correspond to the stretching of $–CH_3$ groups that are bonded to silicon, which is typical of polydimethylsiloxane (PDMS).
- There is a strong, broad absorption between 1070 and 1000 cm^{-1} for the Si–O–Si stretching vibration, with a specific peak at 1020 cm^{-1} aligning with this characteristic of PDMS.
- PDMS typically shows a strong band near 1259 cm^{-1} (often between 800 and 850 cm^{-1} if

visible), attributed to the CH_3 deformation (rocking) on silicon, with the peak commonly found at 1258–1260 cm^{-1}.

- Primary amines ($–NH_2$) frequently exhibit bending modes in the 1600–1650 cm^{-1} range. A small or moderate band near 1640 cm^{-1} can indicate N–H bending, supporting the presence of an amine end group.
- In the low wavenumber region (665, 595, 527, 475, 416 cm^{-1}), the fingerprint region for PDMS often displays Si–O–Si bending, Si–C stretching, and out-of-plane motions. These absorptions affirm the siloxane backbone.
- So ,The presence of Si–O–Si stretching around 1020 cm^{-1} and CH_3 stretching at 2962 cm^{-1} and 2900 cm^{-1} are characteristic features of polydimethylsiloxane (PDMS), - Si–O–Si backbone absorptions (approximately 1020 cm^{-1}),
- N–H stretching observed at 3361 cm^{-1} and bending near 1644 cm^{-1} indicates the presence of an amine-terminated or amine-functionalized PDMS. , - Methyl group stretches at 2962 cm^{-1} and 2900 cm^{-1},- N–H stretching at 3361 cm^{-1} and bending near 1644 cm^{-1}, which are definitive indicators of amine groups.

Conclusions:

- The results of this study indicate that bamboo fabrics can play a significant role in the textile industry as a replacement for petroleum-based or synthetic fabrics, helping to protect the environment. Additionally, bamboo serves as a viable alternative to traditional natural fabrics. The research shows that when treated with various concentrations of silicone compounds (PDMS), bamboo exhibits enhanced qualities, including increased softness, improved fabric strength, and hydrophobic characteristics.

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