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Innovation of Smart Knitted Fabrics for Functional Performance of Sportswear Upon Treatment using Phase Change Material

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Abstract

Sportswear is the most diverse and fastest growing sector in the functional clothing market, which qualifies the athlete to compete to the highest level of performance. Sports textiles are considered one of the most important tech-textiles due to their direct influence on the performance rate and comfort of athletes and improving the sense of comfort. The research aims to produce Smart knitted fabrics that are compatible with warm-up operations before playing any sports to improve the attributes of current clothing using raw materials and building structures that serve the purpose of final use while wearing and using these fabrics. Experiments have been done to find the best samples implemented to produce fabrics suitable for sports warm-up clothing and to study the effect of treatments on the physical and mechanical properties of fabrics and where the quality is assessed for 16 samples treated with different PCMs materials, raw materials, and structural compositions. And it was found that the sample number (D4) implemented in the structural composition (1) Bamboo 70% - 30% cotton in the back and the face material Bamboo 70% - 30% cotton is the best for all functional properties of the fabrics produced under research using variables different study factors And by a quality factor of 84.7%, while the sample number (F2) executed in the structural composition (1) with a back of 100% cotton and the face material 75/35 polyester + viscose filaments 75/24 is the least at all concerning the functional properties of the fabrics produced under research using factors Different studies with a 75.4% quality factor. The researcher found that: treatment with phased change materials has accomplished the following: i) It reduced the air permeability of the fabrics, ii) It increased the water vapor permeability of the fabrics, iii) It increased the fabric's resistance to UV rays, iv) It increased the weight per square meter of fabrics, v) It reduced the thickness of the fabrics, vi) It reduced thermal insulation, and vii) It increased the bursting resistance of fabric.

Keywords: Sportswear, Smart fabrics, Phase Change Material

1. Introduction

1.1. Smart Textiles

The term smart refers to two meanings, which are contemporary – clever or skilled. This name has been associated with many of the tools that we have come to trade and use in our daily lives, such as the smart card, smart cars, smartphones, smart textiles, etc., and the most important thing that distinguishes them is their interactive ability with the environment, including humans.

SMART Textile is identified by the initials for "Self-Monitoring Adoptive and Responsive Textiles". they are those textiles that can sense, then respond, and then find an appropriate reaction towards the surrounding environmental influences, that is, they are those materials or polymers that change their properties according to external conditions or influences. [1-4]

It can be defined as textiles that sense or sense changes occurring or changing in the surrounding environment, and interact according to them, and these changes vary to include mechanical and chemical changes, electrical, thermal, magnetic, and others. [5]

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It is also defined as textiles that can sense and respond and can be adjusted with all kinds of different environments to be more comfortable through an active control mechanism according to the change in the surrounding environmental conditions, and that it can show mechanical properties with an appropriate change, or thermal, optical or electromagnetic properties, in an easy way. In response to external stimuli as well as systems consisting of different devices and materials such as sensors, actuators, and electronic devices together. [6]

1.2. Smart Fabrics System

There are basic components that must be available in Smart Fabrics systems for them to fall under this name, and they are as follows

a) Sensors or sensors.
b) Motors or what are called actuators.
c) The main control unit.

Where the sensors provide a system for detecting signals, and some materials and assemblies act only as sensors, and some act as sensors, actuators, or actuators alike.

To be classified as smart textiles, textiles must contain sensors, an actuator (for active smart textiles), and a control unit (for ultra-smart textiles).

Or textiles contain components such as optical fibers, PCMs, Shape Memory Materials, Chromic Materials, microchips, etc. These components form an integral part of the fabric structure and can be incorporated into the fabric in one of the following stages:

a) During the fiber-spinning process.
b) During the process of weaving fabrics.
c) During the knitting process between the folds of clothes.
d) During the final processing process.

Active (smart) materials can be combined in a spinning bath or with polymer chips before spinning, such as lyocell fibers, which can be modified by mixing electrically conductive components during production to make cellulose fibers electrically conductive. Sensors can also be added during the fabric weaving process, and many have been developed. Of the active compounds that are added to the fabrics during the final processing stages.

Sensors are special devices for detecting signals, where some materials work as sensors only, while others of these materials work as sensors and actuators together. [7]

1.3. Textiles with phase change PCMs (Heat Storage Textiles)

The main objective of storing or regulating heat in textiles is to keep the wearer in a state of thermal functional comfort under a wide range of workloads and ambient atmospheres.

Textiles that store and regulate heat are: new textiles that can absorb and redistribute heat and release heat by changing phase with materials with low melting points according to the change in ambient temperature. [8]

1.3.1. Thermal Energy Storage Technology "TES"

"TES" is defined as the temporary storage of high and low thermal energies for subsequent use, as it works to bridge the time gap between the energy needed and the energy consumed. [9, 10] It is worth noting that among the many different technologies used for heat storage, we find that the latent thermal energy storage technology is the best among these different technologies, due to its ability to provide a high amount of heat storage density in almost isothermal conditions. [11]

1.3.2. Different types of PCMs

Materials with the ability to store thermal energy (PCMs) are theoretically capable of changing their state at an almost constant temperature, and therefore they can store a large amount of thermal energy. Its melting point is from 15 to 35°C. One of the most effective ideas for the effective use of this type of material in the field of textiles, and there are more than 500 types of materials with the ability to heat storage (PCMs), natural and industrial known, and these materials differ from each other in temperature change ranges, and in their heat storage capabilities. [12]

As for the required properties of materials with the ability to heat storage (PCMs) in the fields of spinning and weaving, they are as follows:

- The melting point ranges between 15 and 35 degrees Celsius.
- To generate a high temperature resulting from the fusion
- The difference in temperature between the melting point and the freezing point should be small.
- Be harmless to the environment and have low toxicity.
- To be non-flammable, easily available, and low cost.
- To be able to stabilize the repeat melting and solidification process.

- To have a high capacity for thermal conductivity, and transfer heat effectively. [13]

There are many materials with the ability to store heat (PCMs), which have the capabilities to store heat at different degrees, and they also differ in the temperatures of their transition from one state to another, and among the materials with the ability to store heat (PCMs), which is paraffin wax, which ranges in size from 15-40 µm, which can be laminated and then incorporated into the fibers or used as a coating. The following are some descriptions of PCMs. [14]

1.4. Knitting fabrics

The knitted fabric industry in the world has developed greatly, especially in recent years; This type of fabric has spread rapidly in the modern era in products for indoor and outdoor clothing as a result of the many properties and advantages of these fabrics in addition to their diversity that satisfied different tastes, which led to the prosperity of this industry with the emergence of industrial fibers, the development of natural threads, and the technological development of different types of fabrics. knitting machines.

1.5. Sportswear

It is that clothing that gives the body complete comfort during exercise, and it also prevents any complications that may occur during exercise, and this clothing varies according to the type of sport to be practiced, as well as according to age and gender.

It is the clothing that works to preserve the player's body in ideal conditions for the body to carry out its natural functions when performing physical effort in general and during training and sports activities with extreme stress in particular, in addition to protecting the body from sports injuries associated with some sports activities during sports training or sports matches and competitions In addition, it is distinctive for the game or the sport itself, such as fencing clothes, athletics clothes, hockey clothes, football clothes, and others. [15]

A survey of Olympic athletes regarding the use of functional sportswear showed that: [16]

- 66% of the medical team and 60% of the coaches suggest and support athletes wearing functional clothing during training, and follow this advice knowing its importance.
- 66% of the medical team, 40% of the coaches, and 44% of the Olympic athletes believe that functional clothing has a positive effect on the thermoregulatory process.
- 54% of the medical team and 47% of the Olympic athletes look forward to further efforts of researchers to achieve high performance through functional apparel.

1.5.1. The warming up

The warm-up is the process that the individual performs directly before the competition to prepare and prepare him from the organic, psychological, and technical aspects to ensure his participation in the competition in the best possible condition.

It is the process of heating the muscles using various sports exercises, and whenever the player makes a greater effort for heating, the body temperature rises, and thus the temperature of the muscles rises, so chemical changes are facilitated in them, so the rate of change of substances in the muscles increases as a result of this heat, so the capillaries widen in them and the percentage of blood incoming to them increases.

1.5.2. Warm clothes

Athletes wear warm-up clothes to improve performance by increasing muscle temperature and thus also relaxing them. Some people wear them during exercise to lose weight by increasing sweating. [17] Since the warm-up suit is usually made of impermeable fabrics, this can lead to a critical situation due to a large amount of sweat secretion and the inability to get rid of it through the clothes, which increases the body temperature and becomes thermally inefficient.

1.5.3. The physiological purpose of the warm-up

Warming up is a process that affects the vital systems of the body so that the individual can perform a successful sport, as all body systems work as one unit and are connected, and warming up raises the body temperature.

1.5.4. Characteristics that should be available in warm-up clothes

The properties that should be available in warm clothes are: [18]

- Compatibility and ease of wear.
- High ability to regulate the moisture (ie the transfer and evaporation of moisture) to keep the body dry during exercise.
- The ability to conduct heat and scatter and resist ultraviolet rays, which makes the wearer

feel cool in the summer and warm in the winter.
- Flexibility to provide comfort, ease of movement, tensile strength, and high durability.
- Maintaining the normal level of bacteria on the skin provides a high level of comfort and personal hygiene.

1.6. Textiles and comfort

Conditions of temperature, humidity, and air movement through clothing are among the most important key elements that control a sense of comfort, in addition to other elements such as the generation of static electricity.

Traditional materials such as cotton, silk, wool, polyester, polyacrylic....etc, provide a degree of resistance to body heat loss, which is determined by the number of air pockets in the fibers. To keep the skin temperature at the required level, we must wear and undress according to the outside temperature, so the Ideal fabrics and clothing in terms of thermal comfort should have the following characteristics: [19]

- High thermal resistance to protect from the cold.
- Low resistance to water vapor under thermal stress conditions.
- Accelerate the liquid transfer properties for effective heat transfer and eliminate unwanted texture sensation due to perspiration under conditions of high heat stress.

2. Experimental

2.1. Materials

Pectin medium molecular weight was purchased from Fluka. Stearic acid, sodium lauryl sulfate, dichloromethane (DCM), dicyclohexyl carbodiimide (DCC), potassium carbonate (K_2CO_3), butane tetracarboxylic acid (BTCA), sodium hypophosphite (SHP), and octadecane were purchased from Sigma-Aldrich.

2.2. Methods

2.2.1. Manufacture of textile fabrics

The bi-layer knitted structures were prepared using Polyester microfiber (75/144 diner) with lycra 20 detex in the bonding layer, cotton (40 Ne), Modal (40 Ne), and blended yarn of 50/50 and 70/30 bamboo/cotton (40 Ne) back), in the face were prepared using two groups first polyester75/35 + viscose75/24 and the second 70/30 bamboo/cotton (30 Ne) in the face. All samples were produced in a circular multi-track weft knitting machine (TERROT I3P 148) with a 28-inch diameter, 48 feeders, 18 gauge, and 1680 × 2 needles. In this experimental work, the bi-layer fabric is developed in which the inner layer is made of polyester that is hydrophobic and has a good wicking rate. The outer layers are made up of regenerated fiber such as Modal or bamboo or viscose which has more absorption character and rapid evaporation. The yarn which has to form as an upper layer is fed into the dial needle and as an under layer is fed into the cylinder needle. And the bonding layer uses a needle from the tail and a needle from the cylinder-like interlock gating.

The two bi-layer knitted structures were developed: one is a 6-course repeat in which dial needles knit at the 2^{nd}, and 5^{th} feeders and cylinder needles knit at the 1^{st}, and 4^{th} feeders. The bonding layer takes place in the 3^{rd} and 6^{th} feeders like interlock gating.

The second structure is developed with 6 courses of repeat the tuck frequency takes place at the 1^{st} and 4^{th} feeders, and the cylinder needles form a tuck stitch at the first needle in the first feeder and the second needle in of 4^{th} feeder every repeat. The visual appearance of the structures and the graphical representation of the bi-layer knitted fabric is shown in **Figure 1** and **Table 1**. The sample code and the specifications of produced samples under study are mentioned below in **Table 2**.

2.2.2. Preparation of phase-change material composites

1.5.4.1. Preparation of fatty acid anhydride

10 mmol of stearic acid was dissolved in 2 mL of dichloromethane and stirred in an ice water bath under an atmosphere of argon gas. 5 mM of cyclohexylcarbodiamide (DCC) was then dissolved in 2 mL of dichloromethane. It was then added to the fatty acid while continuing stirring at zero °C for an additional 2 hours. The precipitate was then separated by filtration, then the solvent was vaporized and the anhydride was obtained. [20, 21]

1.5.4.2. Synthesis of fatty acid pectin esters

The pectin esters were esterified as follows: [22] 10 g of pectin and 10 g of stearic acid anhydride were ground with potassium carbonate K_2CO_3 (0.1 equivalent). The mixture was heated in an oil bath for 15-25 minutes at 160° C. The mixture was then cooled to room temperature, washed with chloroform, and filtered a second time. The obtained ester was then dissolved in water and the pH was adjusted to neutral. The finished compound was soaked in deionized water for one day and finally dried for two days. [20, 21]

1.5.4.3. PCM Synthesis

Based on the Fatty Pectin Acid Ester PCMs were prepared as follows by mixing the fatty acid pectin ester with the octadecane compound (n-octadecane), a long-chain paraffin compound (consisting of 18 carbon atoms) in a molar ratio (1:2; polymer to paraffin) at 110°C for 14 hours, and then, it was cooled and used directly to process the fabrics produced. [23]

2.2.3. Fabric treatment

An emulsion of the PCM composite was prepared according to the modified method as follows: 10 g of the PCM composite was transferred into a round flask, then 990 mL of water was added and stirred at 50°C for 10 min. Then 5 g/L of butane tetracarboxylic acid (BTCA) and 5 g/L of sodium hypophosphite (SHP) were added gradually with stirring for an additional 15 minutes. The cloth pieces were immersed in the solution at 40-50°C. The treated fabric was dried at 60°C for 5 minutes, fixed at 130°C for an additional 5 minutes, and then conditioned for a subsequent 24 hours. The treated and untreated fabric was weighed to determine the actual PCM additive percentage (%).

Pickup (%) = $(W_2 - W_1)/W_1 \times 100$

Add-on (%) = $(W_3 - W_1)/W_1 \times 100$

Where W_1 is the weight of the dry fabric before treatment, W_2 is the weight of the wet fabric treated and W_3 is the weight of the dry fabric after treatment.

1.1. Measurements and Analysis

Fourier Transform Infrared Spectroscopy (FT-IR) analysis was utilized to evaluate the phase change materials and their composite to analyze the chemical alterations and interaction phases. Based on the FTIR spectrometer model (JASCO FT-IR-6100), the FTIR spectrum was measured using the ATR technique, and the spectral range of 4000-400 $cm^{-1}$was recorded.

The differential scanning calorimeter analysis was carried out using a DSC 131 Evo (SETARAM Inc., France) device. the standards were used to calibrate the instrument (Mercury, Indium, Tin, Lead, Zinc, and Aluminium). The purge gases employed were nitrous oxide and helium. The test was set up to include a heating zone with a temperature range of 25 to 100°C and a heating rate of 10°C per minute. The samples were weighed using 120 ul of the aluminum crucible.

A parameter used to describe a material and the temperature at which it is intended to function is called the duration index (DI) ($J/cm^3/K$). Equation 1 serves as a gauge to determine the duration of a PCM during a phase transition at a constant temperature.**[24]**.

$DI = \Delta H \rho / \Delta T$ (Eq. 1)

Where T is the temperature difference between the temperature of interest and the measured temperature, H is the enthalpy of PCM change of state, and PCM is the density (ambient, or body temperature).

Equation 2 relates the textile material on which PCM is applied to the overall resistance to dry heat transfer (R), which is the insulation value of clothing systems;

$R = (\Delta T \times A)/H$, (Eq. 2)

Where; A: Areal Material, Temperature Difference between Material's Two Sides, T = TF - TR (Material's Front and Rear), and Heat Flow (H). The unit for clothing insulation adopted from studies of hygienic comfort is "clo" (m^2.°C/W), where 1 clo = 0.155 m2.°C/W (zero (0) clo corresponds to a person in a typical business suit and one (1) clo corresponds to a person wearing a naked body). **[25-28]**.

Thermal Conductivity Measurement and Q-max Measurement (warm/cool feeling).

Before measuring the thermal property of the quick dry. The fabrics were conditioned according to ASTM D1776.

Thermal conductivity refers to the ability of heat transfer through the fabric. In this study, thermal conductivity was measured according to the standard of KES-F7. The thermal conductivity of fabric can be calculated by using the following equation: [29]

$$k = \frac{W \times D}{A \times \Delta T}$$

Where k = thermal conductivity (W/cm・°C); W = Heat flow (W); D = average thickness of samples; A = area of heat plate = 25 cm^2; ΔT = Temperature difference = heat plate temperature (30°C) – cooling base temperature (20°C) = 10°C.

To convert it into SI unit (W/mk):

$$KSI\ (W/mk) = k \times 10^2$$

Q-max Measurement (warm/cool feeling). Q-max is the index indicating the coldness and warmth feeling which affects the sensation of coldness or warmth of skin touching the fabric. It is determined by the heat loss from the skin to the fabric.

Tensile strength and elongation at break are conducted on a tensile strength apparatus type FMCW 500 (Veb Thuringer Industrie Werk Rauenstein 11/2612 Germany) at 25°C and 65 % relative humidity according to the ASTM Test Method D5035-2011. **[30]** The dry crease recovery angle (CRA) was measured according to AATCC Test Method 66 – 2014. **[31]** Fabric roughness was measured using Surface Roughness measuring instrument SE 1700 using ASTM Test Method D 7127 – 13. **[32]** Stiffness was performed using the cantilever apparatus according to ASTM test method D 1388-14e1. **[33]** Air permeability (AP) was evaluated according to ATSM (D 737-96). [34]

Fabric Weight was measured according to the American standard (D3776/D3776M − 09a (Reapproved 2017). [35] as follow: A sensitive scale was used for accuracy (0.001) grams to measure the weight of the square meter, and a sample is cut in the form of a circle with a diameter of 113 mm, which is equal to an area of 100 cm^2, and the average of these readings is taken for the fabrics under study,

Fabric thickness was measured according to the American standard ASTM-D1777-96 [36] as follows: The thickness measuring device was used without a weight Thickness gauge, where there are jaws to put the sample to be measured between them, and the meter shows the reading of the thickness, and the sample is placed between the jaws, and the average reading of the indicator indicating the thickness of the samples.

The air permeability of fabrics was measured according to the American standard. ASTM-D737-18 [34] is as follows: the air permeability test of the fabrics produced under study was carried out using the fabric air permeability device.

A test measuring the ability of fabrics for water vapor permeability and thermal insulation.

Water vapor permeability (WVP) was evaluated according to ATSM (E96/E96M − 16). [37]

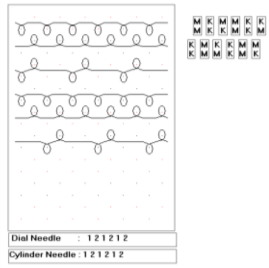
The test was carried out using the Permetest skin model: The sample area is 20 x 20 cm, and the test was carried out at the Institute of Measurement and Calibration according to the standard ISO-11092-14. [38]

Bursting Strength Test was carried out according to ASTM-D3786 using a rubber diaphragm apparatus. [39] The device consists of two rings by which the test piece is tightly fixed over a rubber membrane that is pressurized by liquid or air using a sample diameter larger than the outer diameter of 75 mm for the ring. The sample is fixed without tension and tightly between The two holding rings, then the device is rotated until the pieces, and the explosion resistance readings are recorded according to the American standard.

UPF UV resistance The test was carried out according to AS/NZS 4399:1996 using a UPF spectrophotometer with a sample size of 5 cm2 following Australian Standard AS/NZS 4399:1996. [40]

Differential scanning calorimetry was performed using a Perkin Elmer DSC differential scanning calorimeter under a nitrogen atmosphere (20 ml/min) with heating from 0 to 70°C at a heating rate of 10°C/min and kept for 2 minutes to erase No sample heat storage. Then, the sample was cooled down to 0°C at the same temperature rate as before (10°C/min). Then it was heated again at a heating rate of 10°C/min to 70°C. Then the melting temperature and enthalpy were measured. ASTM-D7426-08(2013). [41]

Table 1: The graphical representation of the bi-layer knitted fabric

<table>
<tr><td>Structure 1</td><td>
<table>
<tr><td></td><td>F1</td><td>F2</td><td>F3</td><td>F4</td><td>F5</td><td>F6</td></tr>
<tr><td>DN1</td><td>-</td><td>X</td><td>-</td><td>-</td><td>X</td><td>X</td></tr>
<tr><td>DN2</td><td>-</td><td>X</td><td>X</td><td>-</td><td>X</td><td>-</td></tr>
<tr><td>CN1</td><td>X</td><td>-</td><td>X</td><td>X</td><td>-</td><td>-</td></tr>
<tr><td>CN2</td><td>X</td><td>-</td><td>-</td><td>X</td><td>-</td><td>X</td></tr>
</table>
Dial needles: Two tracks
DN1-Dial Needles Track 1; DN2-Dial Needles Track 2
Cylinder needles: Two tracks
CN1-Cylinder Needles Track 1; CN2-Cylinder Needles Track 2
Feeders F1, F2 and F6
X Knit stitch; o Tuck stitch; - Miss stitch
</td><td>
</td></tr>
<tr><td>Structure 2</td><td>
<table>
<tr><td></td><td>F1</td><td>F2</td><td>F3</td><td>F4</td><td>F5</td><td>F6</td></tr>
<tr><td>DN1</td><td>-</td><td>X</td><td>-</td><td>-</td><td>X</td><td>X</td></tr>
<tr><td>DN2</td><td>-</td><td>X</td><td>X</td><td>-</td><td>X</td><td>-</td></tr>
<tr><td>CN1</td><td>O</td><td>-</td><td>X</td><td>X</td><td>-</td><td>-</td></tr>
<tr><td>CN2</td><td>X</td><td>-</td><td>-</td><td>O</td><td>-</td><td>X</td></tr>
</table>
Dial needles: Two tracks
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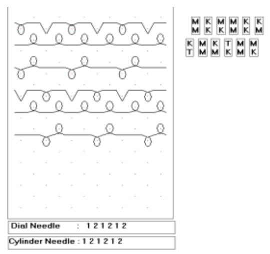
Feeders F1, F2 and F6
X Knit stitch; o Tuck stitch; - Miss stitch
</td><td>
</td></tr>
</table>

Table 2: sample code and specifications of produced sample

Sample No.	Code	F1, F4	F3, F6	F2, F5	Fabric structure
1	B1	polyester 75/35 + viscose 75/24"	polyester 75/144 + lycra 20 detex	Cotton 40/1	Structure 1
2	B2			Modal 40/1	
3	B3			Bamboo-Cotton (40-60%) 40/1	
4	B4			Bamboo-Cotton (70-30%) 40/1	
5	F1			Cotton 40/1	Structure 2
6	F2			Modal 40/1	
7	F3			Bamboo-Cotton (40-60%) 40/1	
8	F4			Bamboo-Cotton (70-30%) 40/1	
9	D1			Cotton 40/1	Structure 1
10	D2	bamboo -cotton (70-30%) 30/1		Modal 40/1	
11	D3			Bamboo-Cotton (40-60%) 40/1	
12	D4			Bamboo-Cotton (70-30%) 40/1	
13	H1			Cotton 40/1	Structure 2
14	H2			Modal 40/1	
15	H3			Bamboo-Cotton (40-60%) 40/1	
16	H4			Bamboo-Cotton (70-30%) 40/1	

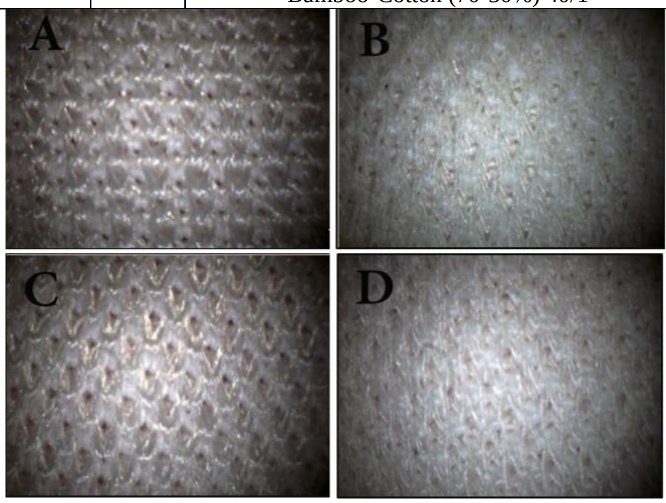


Figure 1: photo image of the bi-layer knitted fabric

a) face of Structure 1 b) back of Structure 1 c) face of Structure 2 d) back of Structure 2

3. Result and disscusion

3.1. Characterization of the prepared phase change material

3.1.1. FT-IR measurement

The prepared phase change material was characterized by the interaction between pectin and stearic acid anhydride using both infrared spectrometries (FT-IR) as shown in Figure 2. Figure 2 shows the shape of the infrared spectrometer for pectin, stearic acid, stearic acid anhydride, and the product of the reaction between fatty acid and pectin. The pectin diagram shows that there are functional groups at 3402, 2932, and 1454 cm^{-1}, representing -OH, -CH, and $-CH_2$. In addition, Figure 3 shows the interaction between pectin and stearic acid anhydride where it shows the shape of its infrared spectrometer where peaks appeared at different wavelengths: at 3437 cm^{-1} (O–H), at 2923 and 2894 cm^{-1} (C–H), at 1725 cm^{-1} (methyl ester, C=O), at 1701 cm^{-1} (fatty acid ester, C=O), at 1630 and 1429 cm^{-1} (COO−), at 1998 and 1125 cm^{-1} (C–O).

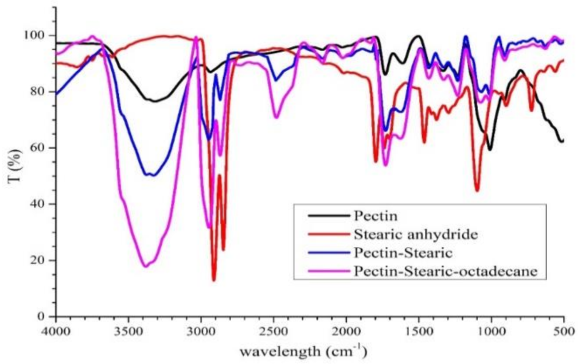


Figure 2: the infrared spectrometer for pectin, stearic acid, and stearic acid anhydride and the product of the product

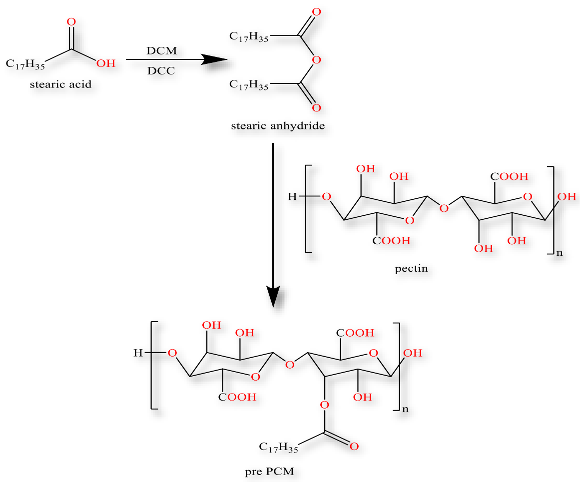


Figure 3: Reaction between pectin and stearic acid anhydride

3.2. Characterization of the treated fabrics

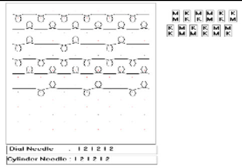
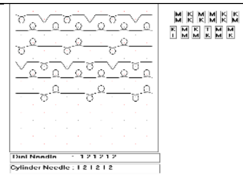
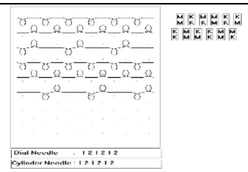
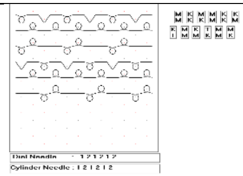
3.2.1. DSC and thermal analysis

Table 3 and **Figure 4** show the results of the differential calorimetry survey of prepared fabrics treated with pectin-stearic acid-octadecane. It can be seen that treatment with this material gives the thermoregulatory property of the fabric. This treatment makes the fabric more comfortable than fabrics treated with only pectin-fatty acid compounds.

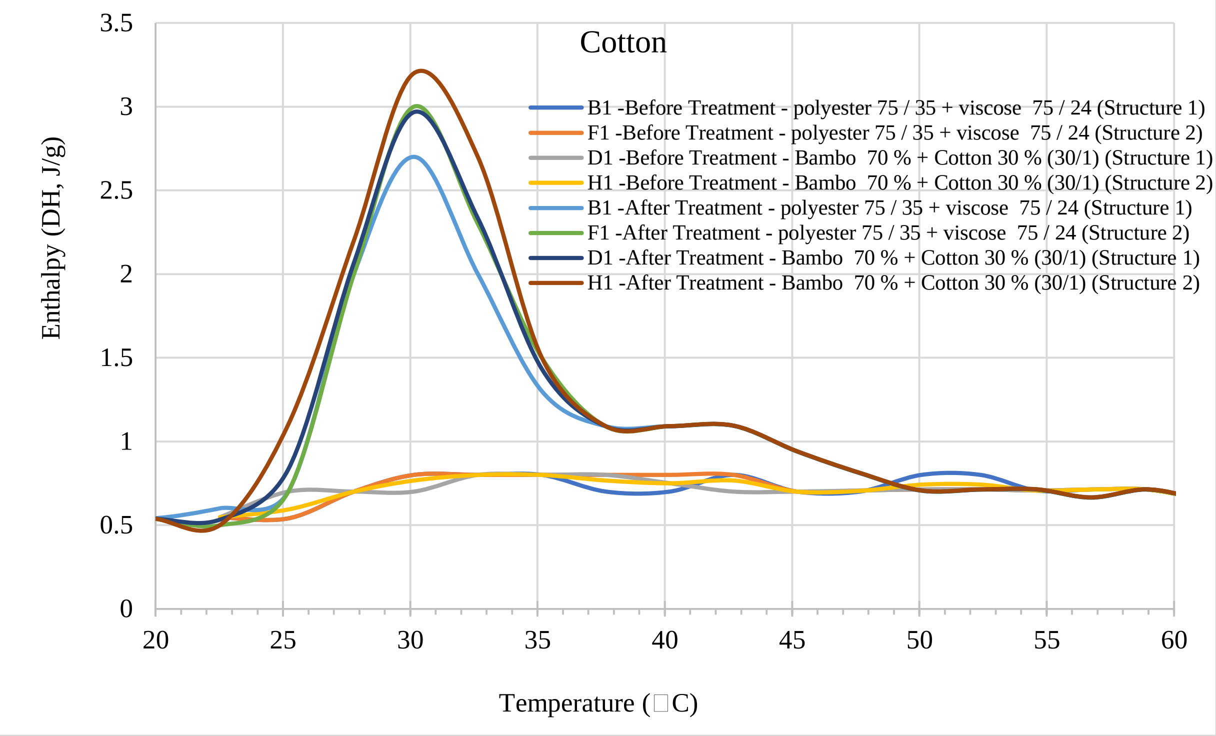
It is clear from **Table 3** and **Figure 4** that the change in the structural structure of the fabric led in turn to the change in the calorific values and thus the duration index. It was noted that the greater the gaps in the structural structure, the higher the aforementioned values. This is because the increase in the number of voids leads to an increase in the working opportunities of the process materials, which gives better results, so the results of structural structure 2 containing the suspended stitch were better than the structural composition 1.

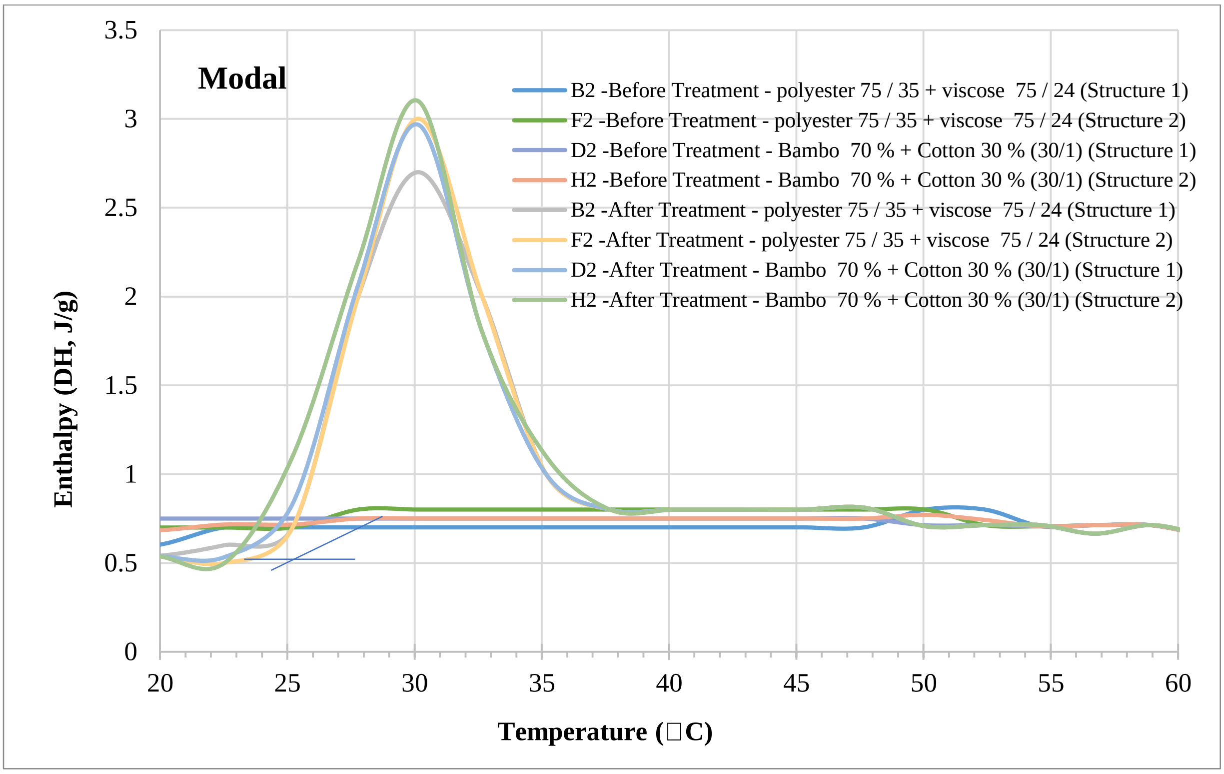
It is clear from **Table 3** and **Figure 4** that the effect of facial yarn difference on heat transfer through double-sided treated fabrics Face 1 (polyester 75/35 + viscose bristles solution 75/24) and Face 2 (Bamboo 70% - Cotton 30% tigress 30/1) through differential scanning (DSC) show a change in facial spinning, in turn, led to the change in calorific values and thus the duration index. Where it was noted that the research samples with a material with a face of (polyester 75/35 + viscose bristles solution 75/24) achieved the lowest percentages in the calorific values in both compositions due to the mixing of bamboo materials 70% - cotton 30% and their high ability to absorb processing materials (PCMs) while the face (polyester 75/35 + viscose bristles solution 75/24) contains polyester, which is one of the industrial raw materials with a round cross-sector and with weak absorption, where water where the percentage of moisture absorption Polyester fibers are about 0.4%, and we note from **Table 3** and **Figure 4** that the best treated samples that achieved the highest results are B4*, followed by F4* The least treated sample, which achieved the highest results, is B4*, followed by the F4 sample, while the F2* sample and the *D2 sample achieved the lowest results in terms of thermal content.

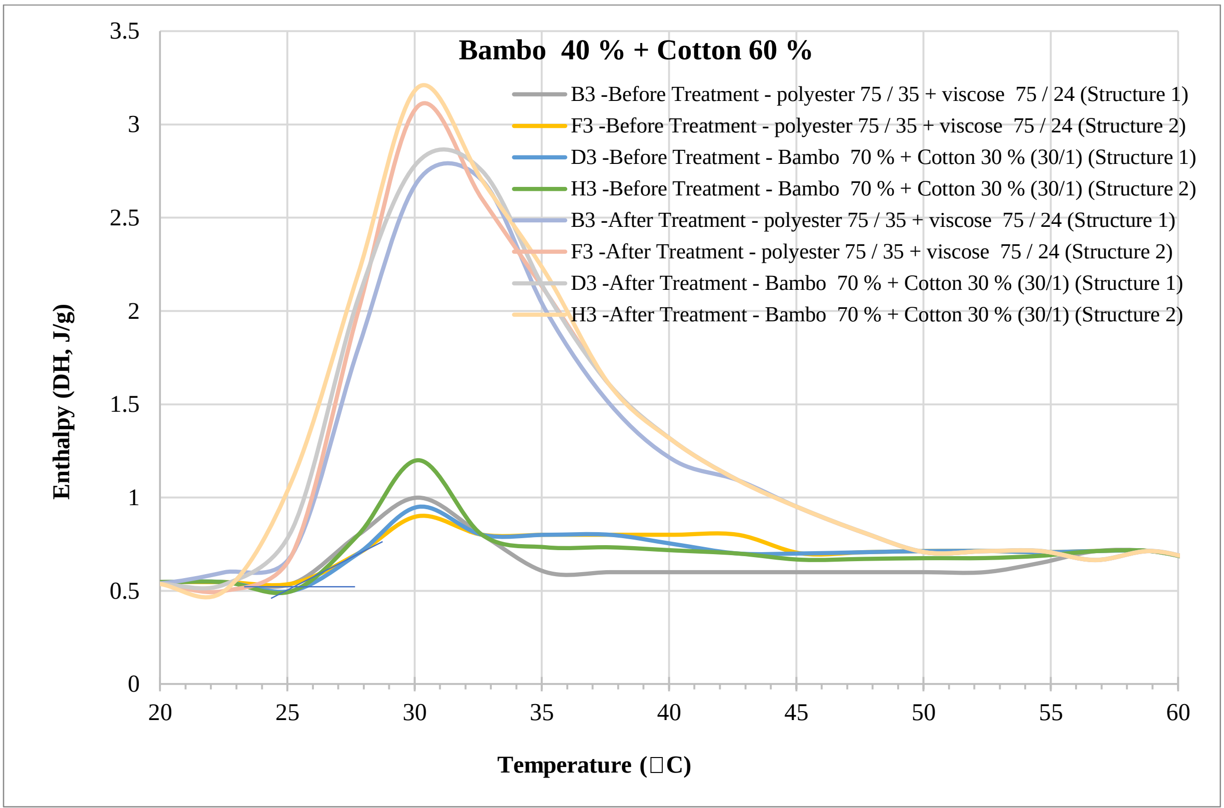
Table 3: Differential Scanning Calometric of Prepared Fabrics Treated with Pectin – Stearic Acid

sample code	Feeders 1-4	Feder (face) 2-5	Feeder (back) 6-3 (40/1)	knitted structure	Second heating						
					Before Treatment			After Treatment			DI * (J/cm^{3}K)
					Melting Temp. (T_o(°C))	Peak Temp. (Tp (°C))	Enthalpy (ΔH (J/g))	Melting Temp. (To(°C))	Peak Temp. (Tp (°C))	Enthalpy (DH (J/g))	
B1	polyester 75 / 35 + viscose 75 / 24	polyester 75 / 144 + lycra 20 detex	Cotton	 Structure 1	25.1	30.1	15.3	25.2	29.9	168.3	11.41
B2			Modal		-	-	-	25.2	29.9	138.4	9.38
B3			bamboo 40% - cotton 60%		25.2	30.2	45.5	25.2	31.2	199.5	13.53
B4			bamboo 70% - cotton 30%		22.3	28.9	74.4	22.5	28.9	228.4	12.60
F1			Cotton	 Structure 2	25.1	30.1	15.6	24.6	30.1	172.1	11.10
F2			Modal		-	-	-	24.6	30.1	142	9.16
F3			bamboo 40% - cotton 60%		25.2	30.1	45.7	24.3	31.2	203.3	12.81
F4			bamboo 70% - cotton 30%		22.8	30.1	75.8	22.5	28.3	231.6	12.78
D1	bamboo 70% - cotton 30% (30 / 1)		Cotton	 Structure 1	22.1	25.3	18.1	22.3	30.1	181.2	9.86
D2			Modal		-	-	-	22.3	30.1	151.1	8.22
D3			bamboo 40% - cotton 60%		25.3	30.2	48.3	24.4	30.3	211.5	13.43
D4			bamboo 70% - cotton 30%		22.8	29.1	77.4	22.1	28.9	240.4	12.91
H1			Cotton	 Structure 2	23.2	29.2	18.6	22.4	30.9	192.4	10.54
H2			Modal		-	-	-	22.4	30.9	161.5	8.85
H3			bamboo 40% - cotton 60%		25.2	30.1	48.7	22.2	30.3	222.7	12.04
H4			bamboo 70% - cotton 30%		23.1	28.9	77.6	20.3	28.4	251.1	12.03

*DI duration index, based on ΔT melting point, body temperature 37°C and average density 0.8 g/cm^3)


Cotton
B1 -Before Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 1)
F1 -Before Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 2)
D1 -Before Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 1)
H1 -Before Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 2)
B1 -After Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 1)
F1 -After Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 2)
D1 -After Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 1)
H1 -After Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 2)
Enthalpy (DH, J/g)
Temperature (□C)
0
0.5
1
1.5
2
2.5
3
3.5
20
25
30
35
40
45
50
55
60


Modal
B2 -Before Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 1)
F2 -Before Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 2)
D2 -Before Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 1)
H2 -Before Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 2)
B2 -After Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 1)
F2 -After Treatment - polyester 75 / 35 + viscose 75 / 24 (Structure 2)
D2 -After Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 1)
H2 -After Treatment - Bambo 70 % + Cotton 30 % (30/1) (Structure 2)
Enthalpy (DH, J/g)
Temperature (□C)
0
0.5
1
1.5
2
2.5
3
3.5
20
25
30
35
40
45
50
55
60



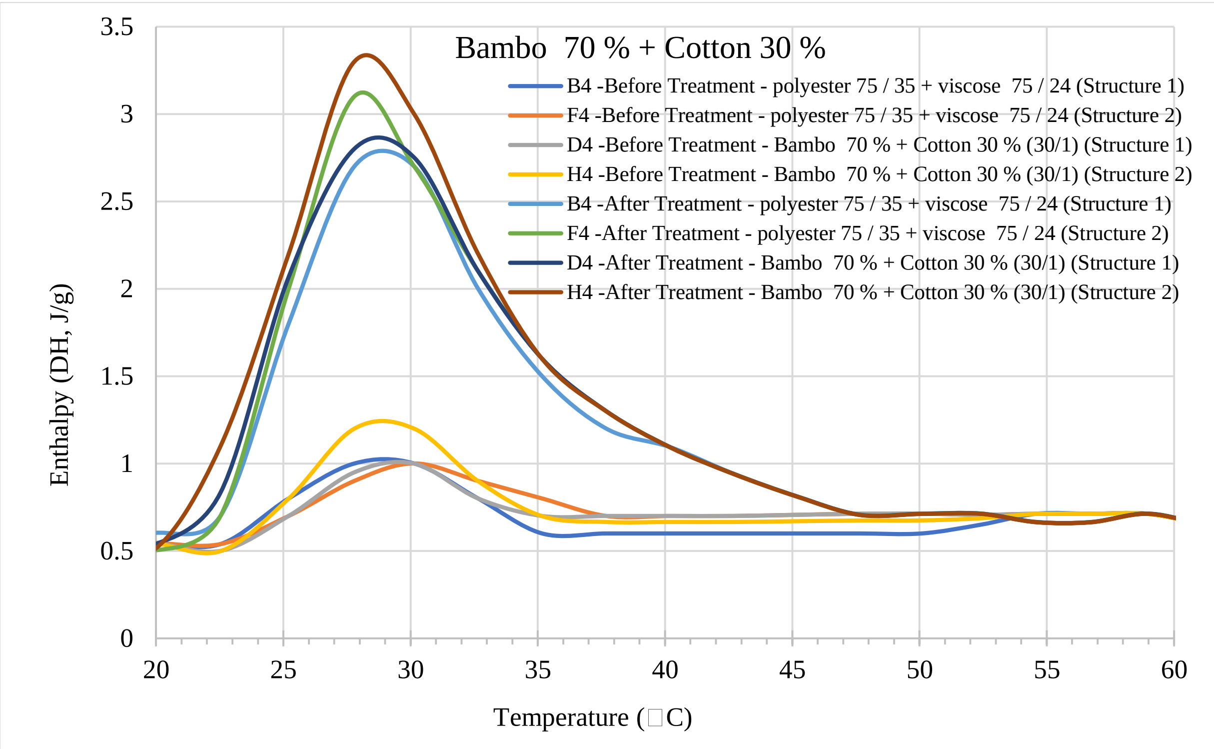


Figure 4: Differential Scanning Calorimetric of Prepared Fabrics Treated with Pectin-Stearic Acid - Octadicane

a) cotton b) modal c) Bambo 40 % + Cotton 60 % d) Bambo 70 % + Cotton 30 %

3.2.2. Physical and mechanical properties

Through **Table 4** and **Figure 5**, it is clear that the effect of treatment with phased change materials on the weight where the weight increases after treatment with phased change materials, and this is observed in all as a result of absorbing and covering the fabrics with a layer of phased change materials.

Through **Table 4** and **Figure 5**, it is clear the relationship between the weight per square meter of fabrics and the structural structure, and it is shown that structural structure 2 is higher in weight than the structural structure1 and this is shown in all samples before and after treatment because the composition 2 contains the hanging stitch, which has the characteristics that it gives a thicker, wider, less rubberized fabric and a heavier weight

Table 4 shows the equation of the regression line and the correlation coefficient for the weight of the square meter before and after treatment at the bond Feeder (3,6) Polyester Microfiber 75/144+ Lycra 20 Detex & Face Nourishing (4-1) Polyester Polyester 75/35+ Viscose IPL Solution 75/24

Through **Table 4** and **Figure 6**, it is clear the relationship between the thickness of the fabrics and the structural structure, it is shown that structural structure 2 is thicker than structural structure 1, and this appears in all samples before and after treatment because the composition 2 contains the hanging stitch, which has the characteristics that it gives a thicker, wider, less rubberized fabric and a heavier weight. [42]

Through **Table 4** and **Figure 6**, it is clear that the effect of treatment with phased change materials on the thickness of fabrics, where the thickness of fabrics decreases after treatment with phased change materials, and this is observed in all where treatment with phased change materials works on the fusion of stitches resulting from shrinkage, reducing the gaps between the hairs and some of them, the gaps between the threads and each other, so compression occurs as a result of the adhesion of the hairs and threads to each other due to the treatment materials, which reduces the thickness.

Table 4 and **Figure 7** it is clear from the relationship between the air permeability of fabrics and the structural structure, where it is shown that structural structure 2 is higher in air permeability than structural structure 1 and this appears in all samples before and after processing because the composition 2 contains the hanging stitch, which creates voids in the fabric structure, which leads to an increase in air permeability.

Through **Table 4** and **Figure 7**, it is clear the relationship between the air permeability of fabrics and the type of back yarn, where is shown that the samples with modal material in the back feeder (2, 5) achieved the highest rate of air permeability, while the research samples with 100% cotton material achieved the lowest values of air permeability before and after treatment, due to the increase in the percentage of irradiation with cotton, which leads to obstruction of air passage by fabric compared to other materials less in irrigation.

Through **Table 4** and **Figure 7**, which it is clear the relationship between the air permeability of fabrics and the difference in the percentage of mixing between cotton and bamboo, it is clear that by increasing the percentage of bamboo material, the values of air permeability before and after processing increase due to the low percentage of cotton material, so the irradiation resulting from it decreases as a result of increasing the percentage of bamboo material, which leads to easy passage of air through the fabric and not obstructing it.

Through **Table 4** and **Figure 7**, it is clear that the relationship between the air permeability of fabrics and the structural structure shows that structural structure 2 is higher in air permeability than structural structure 1 and this appears in all samples before and after treatment because the structural structure 2 contains the suspended stitch, which works to form voids in the fabric structure, which leads to an increase in air permeability.

Through **Table 4** and **Figure 7**, it is clear the relationship between the air permeability of fabrics and the type of back yarn and it was found that the research samples with modal material in the back feeder (2, 5) achieved the highest rate of air permeability, while the research samples with 100% cotton material achieved the lowest values of air permeability before and after treatment, due to the increase in the percentage of irradiation with cotton, which leads to obstruction of air passage by fabric compared to other materials that are less in irrigation.

Through **Table 4** and **Figure 7**, it is clear that the relationship between the air permeability of fabrics and the type of face yarn, and it is shown that the research samples with facial spinning 1 of (polyester 75/35 + viscose bristles solution 75/24) achieved the highest rate of air permeability from the face 2 (bamboo 70% - cotton 30% tigress 30/1) in both formulations before and after treatment due to the difference between the yarn of the two faces as the face (bamboo 70% - cotton 30% 30/1) is equivalent to 177 with the numbering of the denier Higher than the face (polyester 75/35 + viscose bristles solution 75/24), which is equivalent to 150 dinars after application, which leads to a high coverage coefficient, which works in turn to reduce air permeability in addition to the irradiation of mixing two raw materials (bamboo 70% - cotton

30%) while (polyester 75/35 + viscose bristles solution 75/24) are industrial materials free of irradiation and with a regular round cross-section, so there is no obstruction when the air stream passes. Through **Table 4** and **Figure 7**, through which it is clear the relationship between the resistance of fabrics to the air permeability of fabrics and treatment with phased change materials, it is noted that the air permeability decreases after the treatment process, and this is observed in all samples where the treatment works to close the interstitial spaces between the filaments and each other and between the threads in the fabric structure.

Through **Table 4** and **Figure 8**, the relationship between the resistance of fabrics to water vapor permeability and the structural composition becomes clear, as it turns out that structural structure 2 is less in water vapor permeability than structural structure 1 and this appears in all samples because the structure 2 contains stitches Hanging, which works to increase the thickness and weight of the cloth, which causes the absorption of a greater percentage of water vapor. Through **Table 4** and **Figure 8**, the relationship between the resistance of fabrics to water vapor permeability and the structural composition is clear, and it turns out that structural composition 2 is less in permeability to water vapor than structural composition 1 and this appears in all samples and this is due to the containment of composition 2 on The hanging stitch, which works to increase the thickness and weight of the fabric, causes the absorption of a greater percentage of water vapor. Through **Table 4** and **Figure 8**, which illustrate the relationship between the water vapor permeability of fabrics and the type of face yarn, it is clear that the research samples have a face material of (polyester). quilted 35/75 + viscose filament solution 24/75) achieved the highest rate of water vapor permeability than Bamboo 70% - Cotton 30% No. 30/1 in both compositions, due to the hairiness of mixing the two raw materials of Bamboo 70% - Cotton 30% and their high capacity On the absorption, while the polyester quilted 75/35 + viscose filament solution 75/24) are industrial raw materials with a round cross-section, and the water absorption of polyester is weak, as the percentage of moisture absorption of polyester fibers is about .4%.

Through **Table 4** and **Figure 8**, the effect of treatment with phase change water vapor permeability materials is evident. It is shown that water vapor permeability decreases after the treatment process, and this is noted in all samples, The treatment works to close the interstitial spaces between the hairs and each other and between the threads in the fabric structure.

Through **Table 4** and **Figure 9**, the relationship between the resistance of fabrics to explosion and the structural composition is clear, as it is shown that structural composition 1 is higher in the resistance of fabrics to explosion than structural composition 2, and this appears in all samples because the composition 2 contains the hanging stitch that borders The ability of the fabric to elongate, which reduces its resistance to bursting.

Through **Table 4** and **Figure 9**, the relationship between the resistance of fabrics to bursting and the type of backing yarn is clear. It was found that the research samples with 100% cotton material in the back feed (2, 5) achieved the highest resistance of the fabrics. While the research samples made of bamboo material 70% - cotton 30% achieved less resistance to explosion fabrics due to the properties of the natural strength of the filaments, as cotton is the highest raw material in terms of durability, followed by modal and then bamboo. Through **Table 4** and **Figure 9**, the relationship between the resistance of fabrics to bursting and the difference in the mixing ratio between cotton and bamboo becomes clear. Properties Durability properties, as the durability of cotton, is higher than that of bamboo. Through **Table 4** and **Figure 9**, the relationship between the fabrics' resistance to explosion and the structural composition becomes clear. It is shown that structural composition 1 is higher in the resistance of fabrics to explosion than structural composition 1, and this appears in all samples because structural composition 2 contains the hanging stitch, which limits The ability of the fabric to elongate, which weakens it in resistance to the explosion. Through **Table 4** and **Figure 9**, the relationship between the resistance of fabrics to explosion and the type of face yarn is clear. 35 + viscose filament solution 75/24) achieved higher resistance to bursting than face 2 (bamboo 70% - cotton 30%) number 30/1 in both compositions. This is due to the weak durability of natural materials such as mixing bamboo 70% - cotton 30% compared to industrial materials The highest in durability, especially synthetic fibers such as polyester. Through **Table 4** and **Figure 9**, the effect of treatment with phase change materials on the resistance of fabrics to explosion is clear, and it was found that the resistance of fabrics to explosion increases after the treatment process, and this appears in all samples Where the treatment works to increase the weight as a result of the absorption of the treatment in addition to the shrinkage of the accident as a result of the cloth being exposed to the liquid of the treatment solution, and where the treatment also works to close the interstitial spaces between the hairs and some of them and between the threads in the fabric structure.

Table 4: Physical and mechanical properties of manufactured fabric before and after treatment

sample code	Feeder	Feeders 1-4	knitted structure	Feeder 6-3 (40/1)	weight (g/m^2)		Thickness (mm)		Air Permeability ($cm^3/cm^2/sec$)		Water Vapour Permeability (g/h.m2)		Brusting (N)	
					Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment
B1	polyester 75 / 144 + lycra 20 detex	A (Polyester 75 / 35 + viscose 75 / 24)	structure 1	cotton	240.4	244.08	0.701	0.679	74.5	51.7	1.28	0.99	598	622
B2				Modal	243.6	246.3	0.71	0.69	88.7	80.3	1.17	1.12	591	634
B3				bamboo 40% - cotton 60%	245.8	250.22	0.717	0.69	75.5	65.3	1.17	1.11	581	566
B4				bamboo 70% - cotton 30%	255.1	244.9	0.721	0.694	76.7	71.2	1.14	1.07	551	555
F1			structure 2	cotton	247.8	252.86	0.785	0.74	78.3	63.9	1.18	1.04	533	503
F2				Modal	243.3	254.56	0.777	0.75	97	78.3	1.13	1.09	512	458.2
F3				bamboo 40% - cotton 60%	247.3	251.44	0.799	0.69	74.9	59.5	1.16	1.13	430	482.8
F4				bamboo 70% - cotton 30%	251.7	255.36	0.793	0.724	86.7	76.2	1.16	0.99	427.2	431.5
D1		B (bamboo 70% - cotton 30% (30 / 1))	structure 1	cotton	252	255.94	0.824	0.724	50.9	37.5	1.14	1.02	567	520
D2				Modal	262.5	271.56	0.81	0.75	54	47.2	1.15	0.96	533	506
D3				bamboo 40% - cotton 60%	265.1	275.6	0.809	0.724	45.5	37.1	1.16	0.97	521	495.8
D4				bamboo 70% - cotton 30%	269.9	277.04	0.81	0.75	51.7	39.8	1.15	0.98	447.3	458.5
H1			structure 2	cotton	256.8	262.1	0.821	0.79	58	40.3	1.17	1.09	528	509
H2				Modal	269.5	277	0.81	0.783	61.9	46.8	1.09	0.97	454.5	444.8
H3				bamboo 40% - cotton 60%	268.6	279.6	0.831	0.8	60.8	39.6	1.05	1.03	495	447
H4				bamboo 70% - cotton 30%	272.6	280.92	0.841	0.78	60.3	44.4	1.09	0.97	406.2	399.8

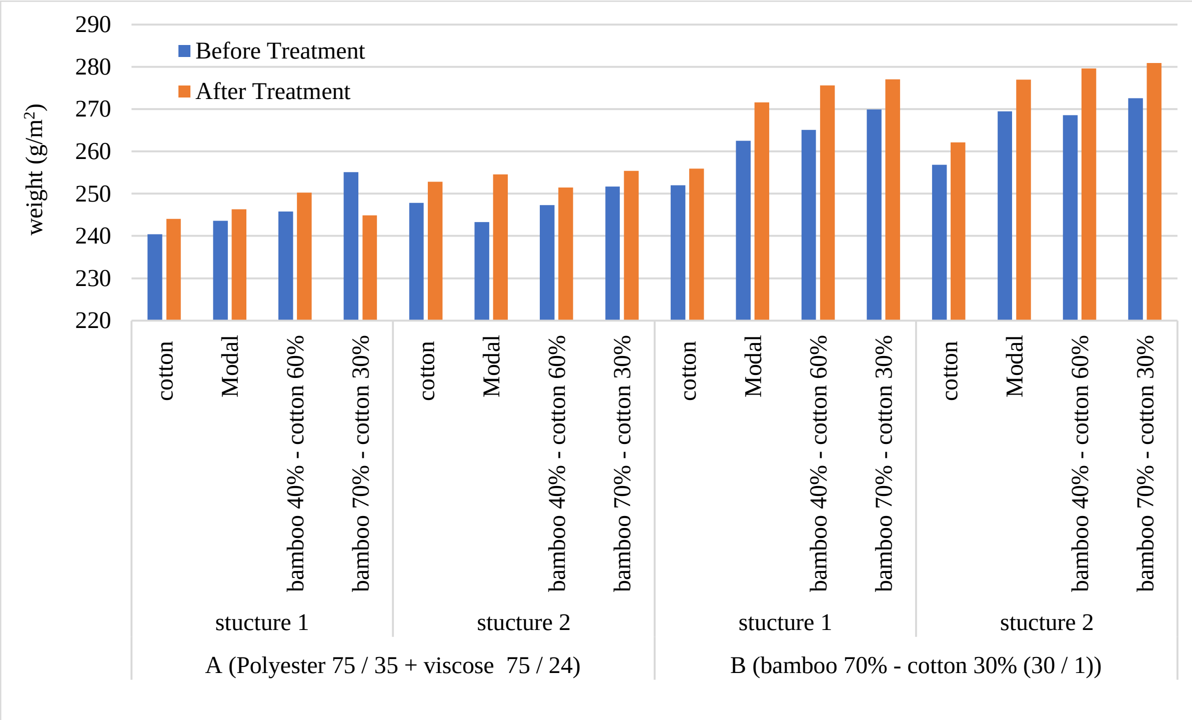


Figure 5: the weight per square meter of fabrics before and after treatment with PCM

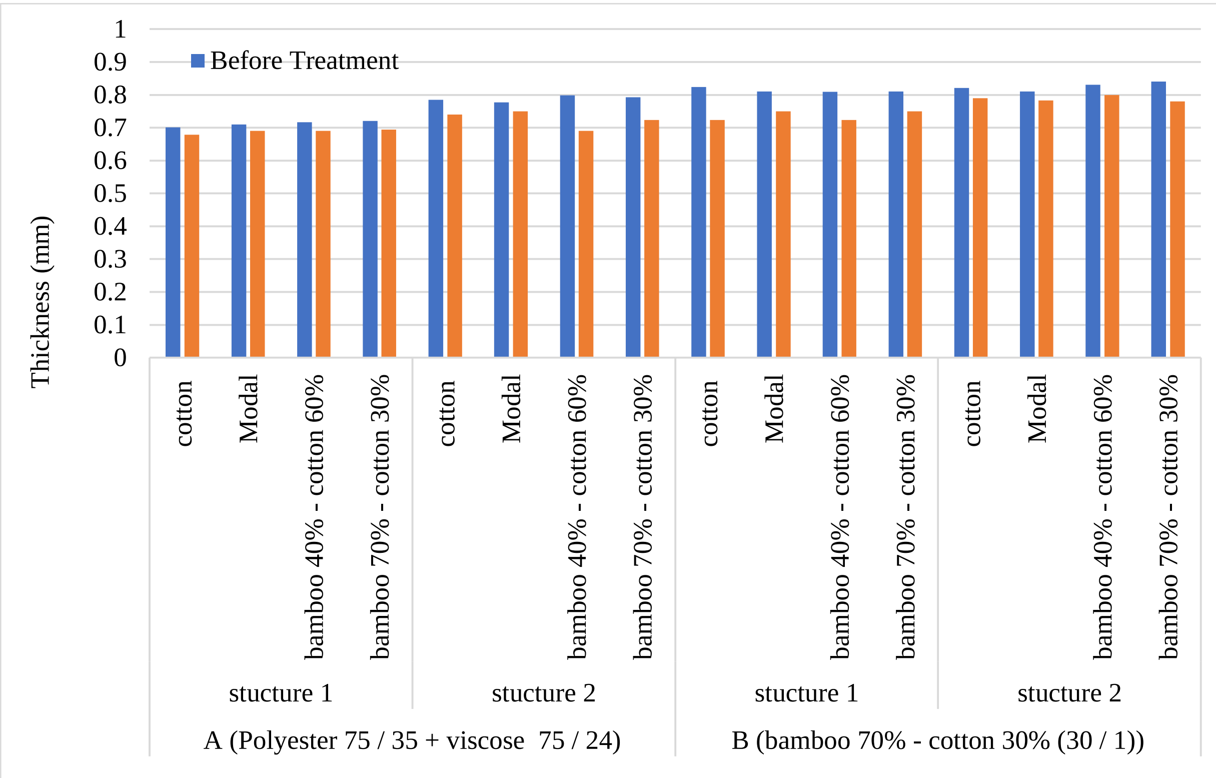


Figure 6: the thickness of fabrics before and after treatment with PCM

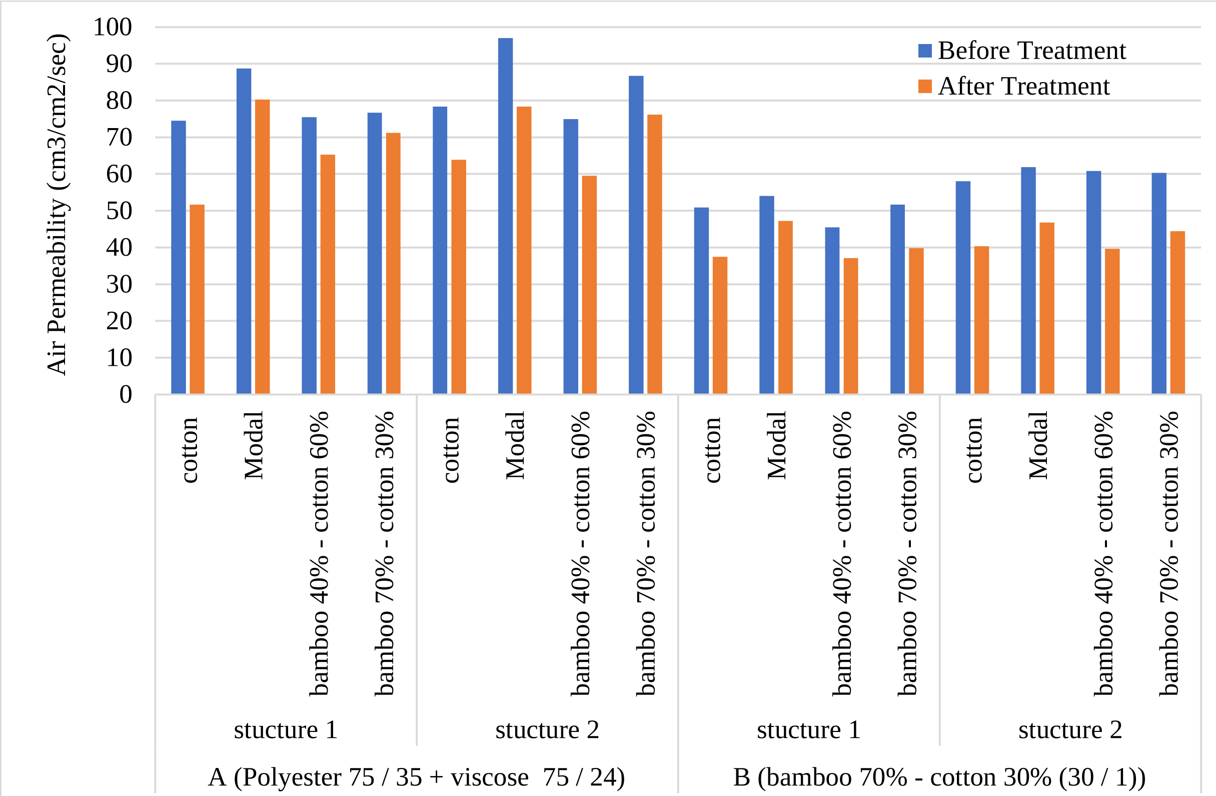


Figure 7: the Air Permeability of fabrics before and after treatment with PCM

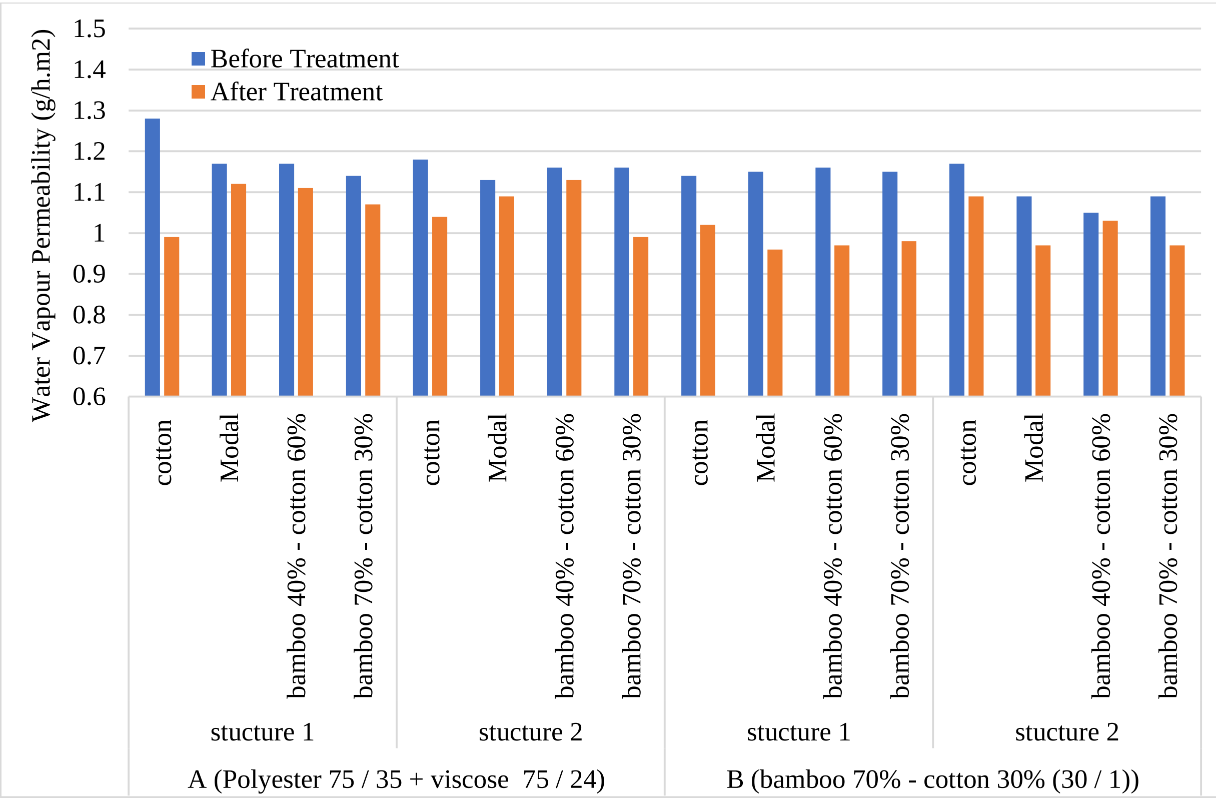


Figure 8: the Water Vapour Permeability of fabrics before and after treatment with PCM

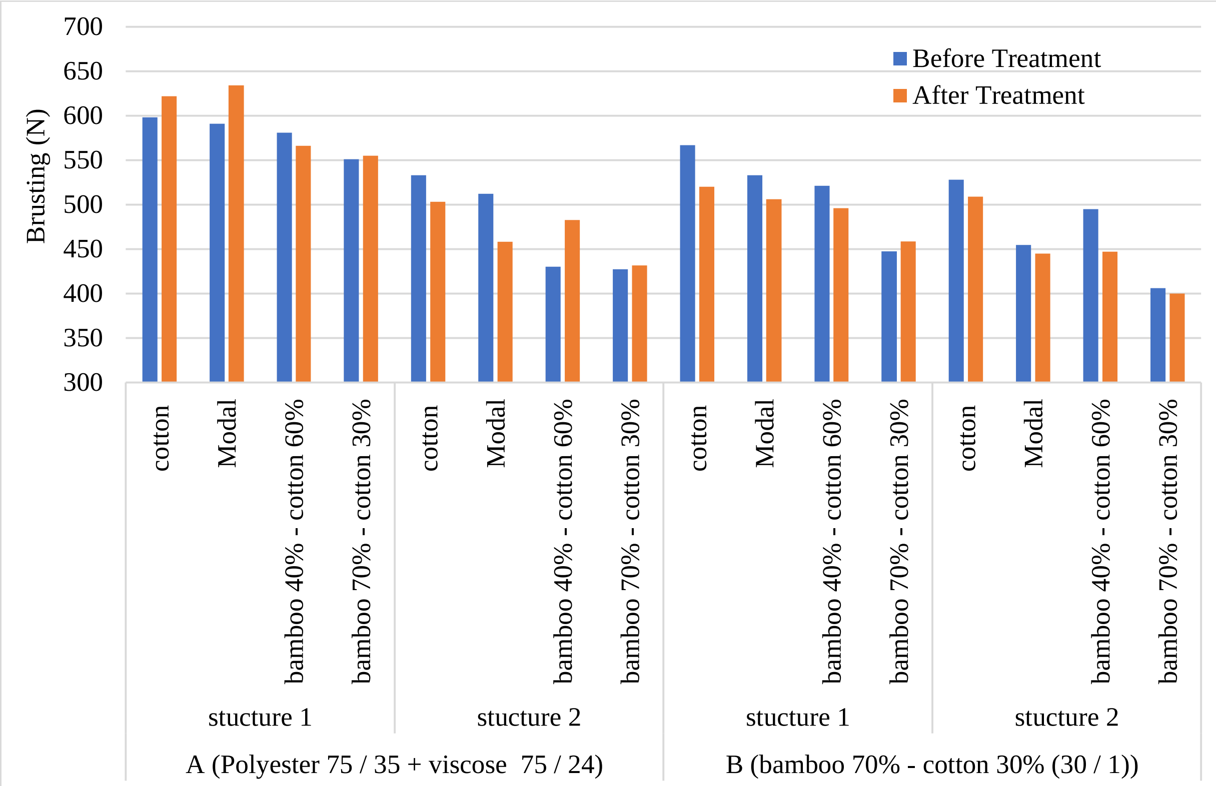


Figure 9: the Brusting of fabrics before and after treatment with PCM

3.2.3. UPF and Thermal insulation

Through **Table 5** and **Figure 10**, it is clear the relationship between the resistance of fabrics to UV rays and the structural structure, it is shown that structural structure 1 is higher in the resistance of fabrics to ultraviolet rays than structural structure 2 and this is shown in all samples because the composition 2 contains the suspended stitch, which increases the transmittance of ultraviolet rays.

Through **Table 5** and **Figure 10**, it is clear the relationship between the resistance of fabrics to ultraviolet rays and the structural structure, where is shown that the research samples with a material of bamboo 70% - cotton 30% in the back feeder (2, 5) achieved the highest resistance of fabrics to ultraviolet rays, while the research samples with 100% cotton material achieved the least resistance of fabrics to ultraviolet rays due to the natural properties that are characterized by bamboo material in UV resistance, which appeared in most of the samples.

Through **Table 5** and **Figure 10**, it is clear the relationship between the resistance of fabrics to ultraviolet rays and the difference in the percentage of mixing between cotton and bamboo, where it is shown that with the increase in the percentage of bamboo material, the values of resistance of fabrics to ultraviolet rays increase before and after treatment, due to the natural properties of bamboo material in resisting ultraviolet rays.

Through **Table 5** and **Figure 10**, it is clear the relationship between the resistance of fabrics to ultraviolet rays and the structural structure is shown that structural structure 1 is higher in the resistance of fabrics to ultraviolet rays than the structural structure2 and this appears in all samples because the composition 2 contains the suspended stitch, which increases the transmittance of ultraviolet rays through the fabric.

Through **Table 5** and **Figure 10**, it is clear that the relationship between the resistance of fabrics to ultraviolet rays and the structural structure shows that the research samples with a material of bamboo 70% - cotton 30% in the back feeder (2, 5) achieved the highest resistance to ultraviolet rays, while the research samples with 100% cotton material achieved lower values of resistance to ultraviolet rays due to the natural properties that are characterized by bamboo material in UV resistance, which appeared in most of the samples.

Through **Table 5** and **Figure 10**, the relationship between the resistance of fabrics to ultraviolet rays and the type of face yarn is clear. 75/35 + viscose filament solution 75/24) achieved the lowest resistance of fabrics to ultraviolet rays from (bamboo 70% - cotton 30% No. 30/1) in both compositions. This is due to the difference between the number between the two-face yarns, as the face (bamboo 70%) - 30% cotton 1/30) is equivalent to 177 denier numbering higher than the face (draped polyester 75/35 + viscose filament solution 75/24), which is is equivalent to 150 denier after application, which leads to a higher coverage coefficient, which in turn works to reduce the transmittance of UV rays Violet in addition to the natural properties of the bamboo raw material, as it increases the percentage of bamboo filaments in the sample, its ability to resist ultraviolet rays increases, in addition to the property of filamentation present in natural materials, which somewhat impedes the passage of ultraviolet rays, while (polyester 75/35 + viscose filaments solution 75/24) synthetic materials with a rounded cross-section that reduces the blockage of ultraviolet rays because there is no hairization.

Through **Table 5** and **Figure 10**, the effect of treatment with phase change materials on the resistance of fabrics to ultraviolet radiation is clear, as the resistance of fabrics to ultraviolet radiation increases after treatment with phase change materials This is observed in all samples, where the treatment works to fill the interstitial spaces between the hairs and some of them, and between the threads in the fabric structure.

Through **Table 5** and **Figure 11**, the relationship between the resistance of fabrics to thermal insulation and the structural composition becomes clear. It turns out that Structural Structure 2 is more resistant to thermal insulation than Structural Structure 1, and this appears in all samples. This is due to Structure 2 containing the hanging stitch, which works to form air pockets as well as increase the thickness, thus increasing the amount of thermal insulation.

Through **Table 5** and **Figure 11**, the relationship between the resistance of fabrics to thermal insulation and the type of backing yarn is clear. Resistant to thermal insulation, due to the felting of the cotton raw material, where the increase in hiring works to close the interstitial spaces between the threads and some of them.

Through **Table 5** and **Figure 11**, the relationship between the resistance of fabrics to thermal insulation and the structural composition is clear. It is shown that structural composition 2 is higher in the resistance of fabrics to thermal insulation than structural composition 1, and this appears in all samples before and after treatment, and this is due to the containment of composition 2 On the hanging stitch, which creates air pockets, as well as increasing the thickness, thus increasing the amount of thermal insulation.

Through **Table 5** and **Figure 11**, the relationship between the resistance of fabrics to thermal insulation and the type of backing yarn is clear. The samples are made of 70% bamboo - 30% cotton in the backing (2, 5).) achieved the highest resistance to thermal insulation, while samples of modal material achieved 100% of the lowest resistance of fabrics to thermal insulation, due to the increase in the percentage of bamboo material on both sides, which has high thermal insulation properties compared to the weave property of cotton.

Through **Table 5** and **Figure 11**, the relationship between the resistance of fabrics to thermal insulation and the type of face yarn is clear. /35 + viscose filament solution 75/24) achieved the lowest resistance of fabrics for thermal insulation from Bamboo 70% - Cotton 30% No. 30/1 in both compositions, due to the special filament mixing of two raw materials, Bamboo 70% - Cotton 30%, as well as thermal insulation properties The high quality of bamboo material, while (polyester woven 75/35 + viscose filament solution 75/24) are industrial materials with a round cross-section.

Through **Table 5** and **Figure 11**, the effect of treatment on the resistance of fabrics to thermal insulation is clear, and it is shown that the resistance of fabrics to thermal insulation decreases after the treatment process, and this is noted in all samples, The treatment increases the heat content and thermal conductivity during the heating process on the device.

Table 5: UPF and thermal insulation of manufactured fabric before and after treatment

sample code	Feeder	Feeders 1-4	knitted structure	Feeder 6-3 (40/1)	UPF		Thermal insulation (Rsi) (Km2/W)	
					Before Treatment	After Treatment	Before Treatment	After Treatment
B1	polyester 75 / 144 + lycra 20 detex	A (Polyester 75 / 35 + viscose 75 / 24)	structure 1	cotton	21.2	26.8	15.6	12.9
B2				Modal	23.3	30.1	18.3	11
B3				bamboo 40% - cotton 60%	33.4	39.3	15	9.7
B4				bamboo 70% - cotton 30%	34.6	39.8	14.6	11
F1			structure 2	cotton	17.2	20.6	15.4	11.4
F2				Modal	20.9	21.6	18.9	14.6
F3				bamboo 40% - cotton 60%	27.9	30.1	14.2	7.9
F4				bamboo 70% - cotton 30%	30.3	33.2	15.4	11.5
D1		B (bamboo 70% - cotton 30% (30 / 1))	structure 1	cotton	36.2	45.4	19.3	15
D2				Modal	50.6	56.7	21.2	17.8
D3				bamboo 40% - cotton 60%	53.5	63.1	18.2	10.4
D4				bamboo 70% - cotton 30%	69.5	78.8	24.8	20.4
H1			structure 2	cotton	31.1	34.9	26	20.9
H2				Modal	41.2	48.4	24.8	16.6
H3				bamboo 40% - cotton 60%	50.5	57.9	24.2	19.4
H4				bamboo 70% - cotton 30%	56.2	71.9	30.6	17.3

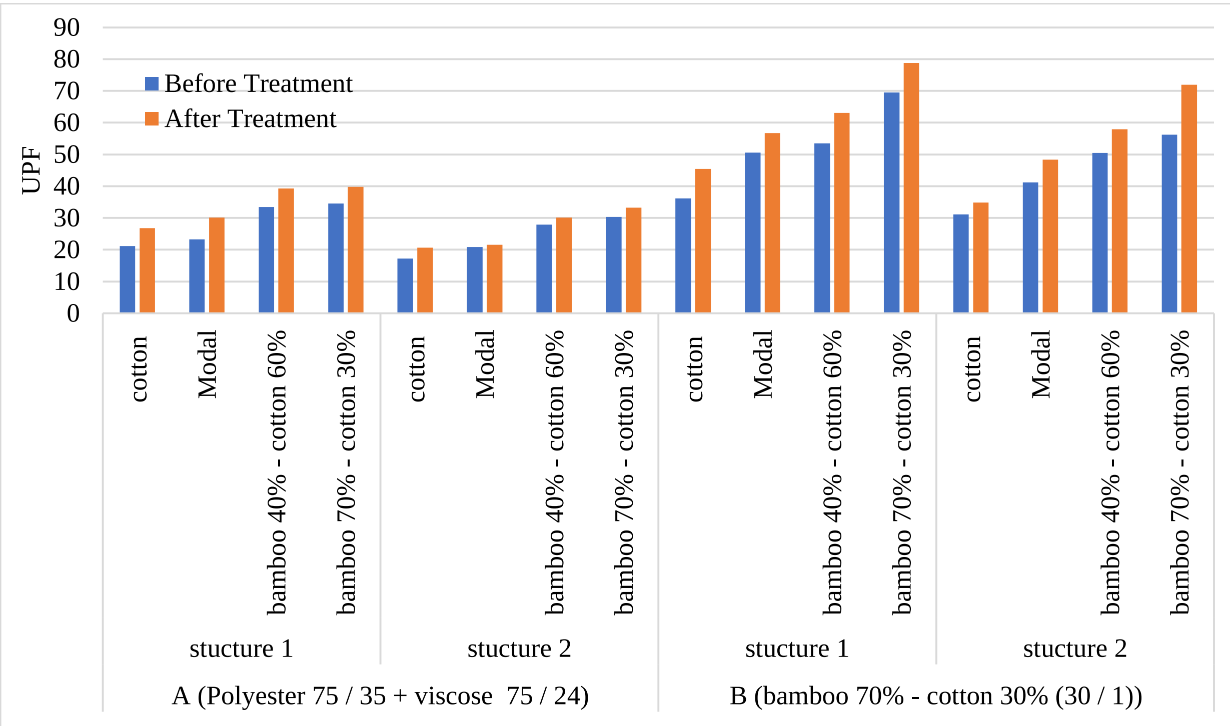


Figure 10: UPF value of manufactured fabric before and after treatment

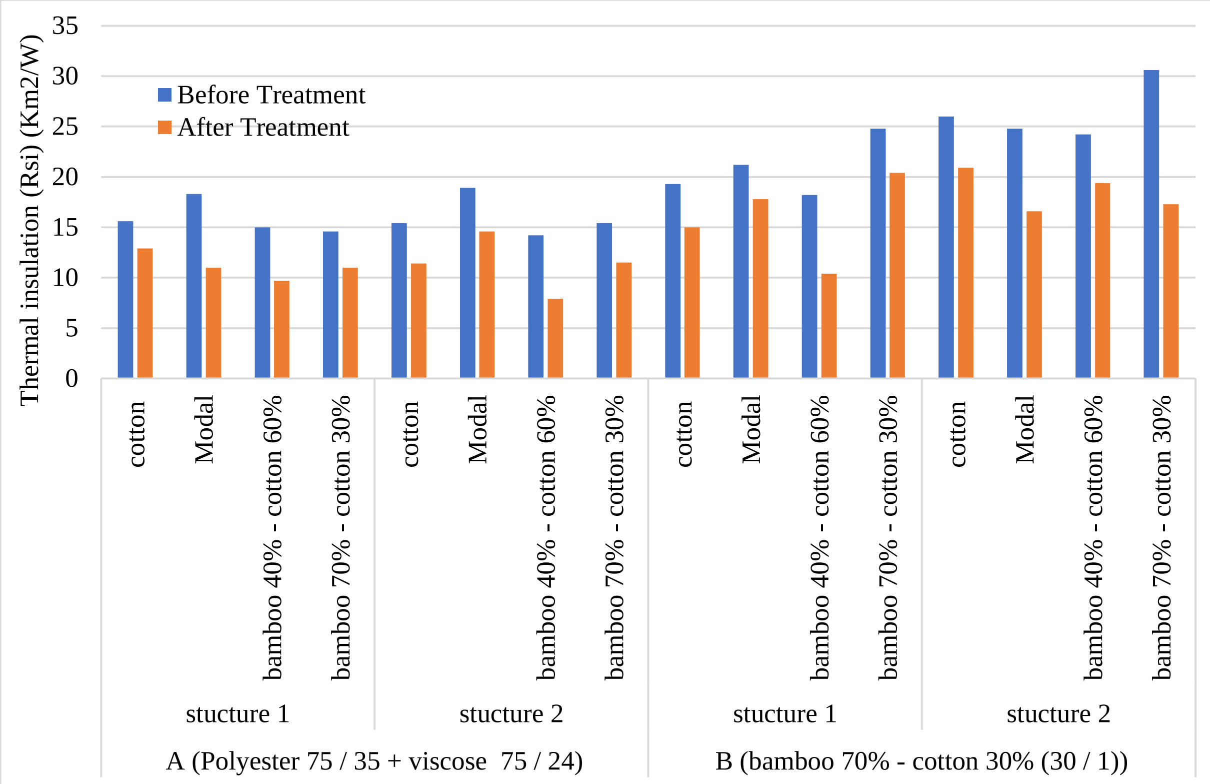


Figure 11: Thermal insulation

1.7. Evaluation of the overall quality of the produced fabrics treated with the phase change materials under study

An assessment was made of the quality of the fabrics produced under research for their functional suitability, to choose the best sample, and multi-axis radar charts were used to express the quality assessment of the samples produced under research through the use of the following properties:

- Weight per square meter of fabric.
- Water vapor permeability.
- The thickness of the cloth.
- DSC enthalpy
- Fabric resistance to the explosion.
- thermal insulation
- Resistance of fabrics to ultraviolet rays
- Percentage increase in weight as a result of absorption after immersion %

By converting the results of the average measurements of these properties into relative comparison values (without units) ranging from (0-100).

Since the larger comparative value is the best with all the previous different properties except for weight and thickness, the lower comparative value is the best, and the following equations were used to calculate the relative comparative value.

$$QF = \frac{X}{X_{Max}} \times 100$$

Where: X (read each sample separately), X_{Max} (highest reading)

Note: The previous equation was used to calculate the relative comparative value for all properties except for thickness and thermal insulation.

$$QF = \frac{X_{Min}}{X} \times 100$$

Where: X (read each sample separately), X_{Min} (less read)

Note: The previous equation was used to calculate the relative comparative value of the thickness and weight characteristics

Table **6** and **Figure 12**, conclude the following:

- The sample (B2) with the modal back yarn produced with the structural composition (1) and the face yarn is woven polyester 75/35 + viscose filaments solution 75/24 is the best in terms of all functional properties with a quality coefficient of 83.3% while sampling No. (B1) produced with the structural composition (1) was the face yarn, woven polyester 75/35 +

viscose filaments solution 75/24, the lowest in terms of all functional properties, with a quality factor of 78.1%

- The sample (F4) with a bamboo backing material of 70% - 30% cotton produced with the structural composition (2) and the face yarn is plaited polyester 75/35 + viscose filaments 75/24 is the best for For all functional properties, with a quality factor of 80.2%, while sampling No. (F1) with a 100% cotton backing material produced with the structural composition (2) facial yarn, woven polyester 75/35 + viscose filaments 75/24, is the lowest for all functional properties, with a quality factor of 74.9%.\
- The sample (D4) with a backing of bamboo 70% - cotton 30%, produced with the structural composition (1) and face yarn bamboo 70% - cotton 30% is the best for all functional properties with a quality factor of 84.7% While the sample (D1) with a cotton back and produced with the structural composition (1) bamboo face yarn 70% - 30% cotton was the lowest for all functional properties with a quality factor of 73%.
- Sample No. (H4) with the back of bamboo 70% - cotton 30% and produced with the structural composition (2) and the face yarn bamboo 70% - cotton 30% is the best for all functional properties with a quality coefficient of 81.4%, while the sample (H2) with a modal back and produced with the structural composition (2) and face yarn bamboo 70% - cotton 30% was the lowest for all functional properties with a quality factor of 77.4%.
- Sample No. (D4) executed with the structural composition (1) bamboo 70%- 30% cotton and face yarn and face yarn bamboo 70% - 30% cotton is the best on The release of all functional properties of the fabrics produced under research using variables and various study factors with a quality factor of 84.7%, while the sample No. (F1) implemented with the structural composition (1) with a 100% cotton back

The face yarn, woven polyester 75/35 + viscose filament solution 75/24, is the lowest of all in terms of all the functional properties of the fabrics produced under research using various study factors, with a quality factor of 75.4%.

Table 6: the overall quality of the produced fabrics treated with the phase change materials

	weight (g/m2)	**Thickness (mm)**	**Air Permeability (cm3/cm2/sec)**	**Water Vapour Permeability (g/h.m2)**	**Brusting (N)**	**UPF**	**Thermal insulation (Rsi) (Km2/W)**	**The percentage of weight gain as a result of absorption**	**DI**	**Quality Factor (%)**	**ascending number**
*B1	100	100	64	88	98	34	61	72	84	78.15	12
*B2	99.1	98.4	100	99	100	38	72	93	69	83.36	2
*B3	97.5	98.4	81	98	89	50	81	77	100	82.03	4
*B4	95.7	97.8	89	95	88	51	72	86	93	83	3
F1*	96.5	91.8	80	92	79	26	55	72	82	74.95	16
F2*	95.9	90.5	98	96	72	27	71	96	61	78.65	10
F3*	97.1	98.4	74	100	76	38	38	78	99	77.74	13
F4*	95.6	93.8	95	88	68	42	56	89	95	80.23	7
D1*	95.4	93.8	47	90	82	58	73	83	73	77.13	14
D2*	89.9	90.5	59	85	80	72	86	94	61	79.66	8
D3*	88.6	93.8	46	86	78	80	50	81	99	78.15	11
D4*	88.1	90.5	50	87	72	100	99	82	95	84.91	1
H1*	93.1	85.9	50.2	96.5	80.3	44.3	100	85.1	77.9	79.3	9
H2*	88.1	86.7	58.3	85.8	70.2	61.4	79.4	100.8	65.4	77.4	15
H3*	87.3	84.9	49.3	91.2	70.5	73.5	92.8	89.5	89	80.9	5
H4*	86.9	87.1	55.3	85.8	63.1	91.2	82.8	91.2	88.9	81.4	6

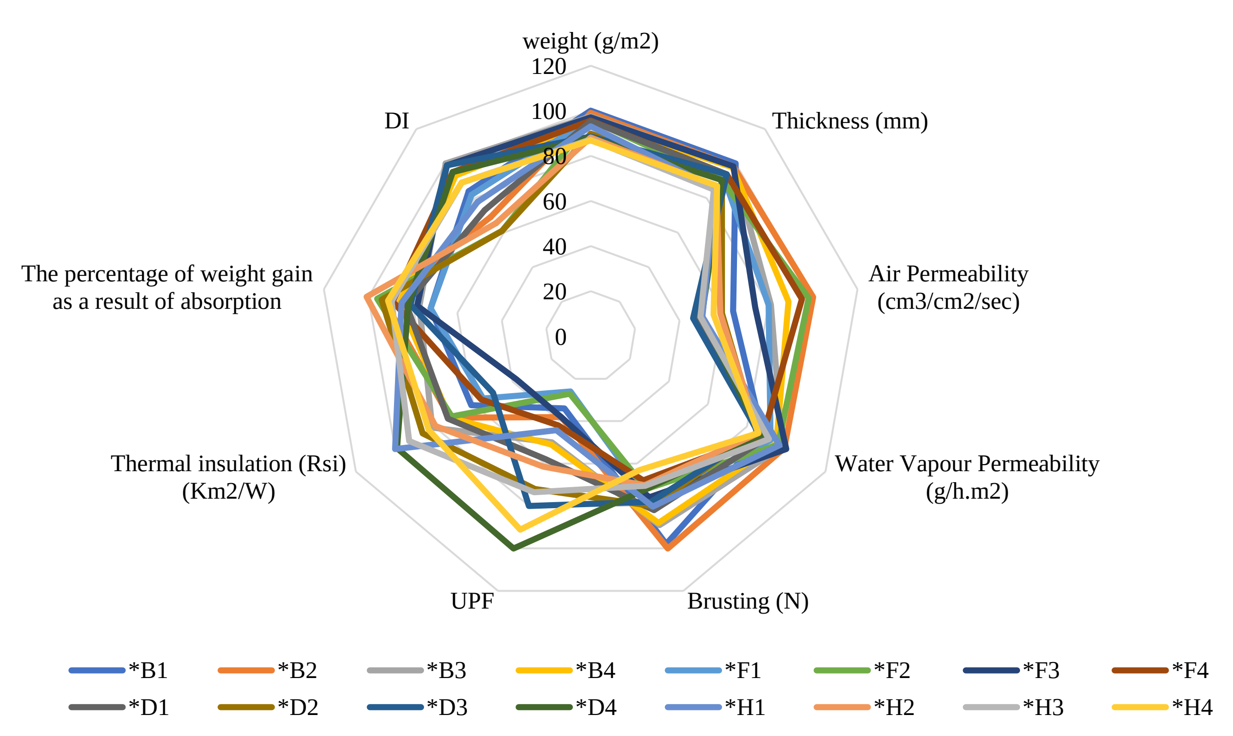


Figure 12: Evaluating the quality of fabrics for the executed research samples according to the quality factor

4. Recommendation

1- Interest in the field of textiles used in sportswear, which did not get the right of research and study
2- Carrying out various studies on sports fabrics, they are tested by simulating actual conditions of use to reach the efficiency of functional performance with economic quality.
3- Working on the use of advanced and different scientific research systems to reach new chemical compositions of phase change materials, to open a broader horizon in other areas and functional uses for these types of fabrics so that they can be produced locally. And to prepare Egyptian standard specifications for these different types of fabrics, so that Egypt would have Middle Eastern and African leadership in this field.
4- The need to provide machinery and mechanical equipment that are compatible with these types of modern types of raw materials, and the need to provide research laboratories equipped with high-precision laboratory devices to conduct laboratory experiments and tests on these new types of raw materials.
5- Conduct field research to find out the efficiency of the performance of this type of fabric and the extent of comfort it achieves for the wearer through the various sports teams.
6- Establishing a database of all scientific departments in practical colleges containing industrial problems faced by the owners of industrial projects so that they can be research points for researchers so that they can find scientific and economic solutions to these problems.

5. Conflict of interest

The authors declare that there is no conflict of interest

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