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Characterization of the Thermal and Physico-Mechanical Properties of Cotton and Polyester Yarns Treated with Phase Change Materials Composites

**Marwa A. Ali [a], Ahmed G. Hassabo [b*], Khaled M. Seddik [c],
Sarah Yahia [a], and Nermin M. Aly [a]**

[a] *Spinning and Weaving Engineering Department, Textile Research and Technology Institute, National Research Centre, 33 El-Buhouth St., Dokki, Giza, Egypt, P.O.12622.*

[b] *Pre-treatment and Finishing of Cellulose-based Textiles Department, Textile Research and Technology Institute, National Research Centre, 33 El- Buhouth St., Dokki, Giza, Egypt, P.O.12622.*

[c] *Clothing and Knitting Industrial Research Department, Textile Research and Technology Institute, National Research Centre, 33 El- Buhouth St., Dokki, Giza, Egypt, P.O.12622.*

Abstract

Textiles integrated with phase change materials (PCMs) are gaining increasing consideration recently in the textiles market due to their smart thermal performance. PCMs are thermal energy storage materials, when combined in textiles they can sense the environmental conditions changes and react to provide the required equilibrium. In this work, four yarn samples were produced from different materials namely; cotton Giza 94, cotton Giza 86, cotton Giza 86/polyester and polyester fibres, and were treated with PCMs composites to acquire them with thermoregulation property. The yarns were treated with Octadecane as PCM loaded on pectin stearate and/or alginate stearate. The thermal and physio-mechanical properties of the yarns were characterized to evaluate their functional performance. The results were statistically analysed using ANOVA at $P \leq 0.05$ significance level. The results revealed that all treated yarns with PCM composites showed smart behaviour with imparting the thermoregulation property; they exhibited higher latent heat and Duration index (DI) compared to the untreated yarns. Also, the yarns coated with pectin/alginate/stearic offered higher latent heat and DI more than the yarns coated with pectin/stearic and the yarns coated with alginate/stearic as hosting materials. Moreover, all yarns coated with the PCM composite materials showed preferable results and are arranged as follows; cotton G86/polyester, polyester, cotton G86, and cotton G94. The PCM composite treatments showed a highly-significant effect on most of the physical and mechanical properties of yarns, especially polyester and cotton G86/polyester yarns.

Keywords: Cotton yarn, Polyester yarn, Octadecane, DSC analysis, PCM composite.

1. Introduction

Thermoregulation property is one of the important aspects that has attracted the attention of many researchers, who seek to provide it in various garments and insulation applications where there is a temperature variation to increase the thermal comfort. In general, comfort can be classified into; Thermo-physiological comfort, sensorial comfort, psychological comfort and garment fit [1, 2]. The human body is a thermoregulated organism; it produces heat, CO_2 and H_2O through food metabolism and muscle activity. Thermal comfort is related to the balance between perspiration and heat generated and dissipated by the body, it depends on the sensitivity of the internal and external (skin) temperature [3-5]. Textile fibres such as cotton, silk, wool, polyester,

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acrylic…*etc.*, are offering a degree of resistance to body heat loss, which is determined by the air gaps found in the fabric to maintain skin temperature to the desired level. The textile market is in major need of smart fabrics that can suit all climatic conditions. Smart textiles are a type of textiles that are capable of reacting to the stimuli rendered internally or externally to keep the desired level of specified applications. These features could be brought up in the fibres stage, designing stages or by applying special finishes [3].

Phase change materials (PCMs) are functional materials with the high latent heat of fusion and crystallization that melt and solidify at nearly close temperatures [6, 7]. PCMs are classified into; sensible heat storage materials that undergo temperature change during phase change like water, steel and stone…*etc.*, and latent heat storage that undergoes phase change with slight temperature changes [5]. Latent heat storage materials are the most promising because they offer a high density of thermal energy storage and ease of operation at an approximate isothermal condition. They can convert from solid to liquid to gas and vice versa [3]. PCMs are widely used in medical and health care applications, heat pumps, thermal energy storage, solar engineering, microprocessors, microclimate control…*etc.* Utilization of PCMs in textiles is the most widely used method in making thermoregulated smart textiles to provide thermal comfort [6, 8]. These materials are used to attain automatic adapting properties of textile materials to be able to sense the environmental conditions and react to the required thermal change and equilibrium [5, 6, 8].

The PCMs used in textiles must lie in the specified temperature intervals such as; heat-absorbing temperature from 20-40˚C and heat-releasing temperature from 30-10°C [3]. Several techniques are used to incorporate PCM into textiles including coating, lamination, finishing, melt spinning, injection moulding, foams…*etc.* [3, 5]. They can be directly incorporated into fibres or can typically be applied to fabrics through the coating process [5]. The applications of PCMs in the field of textiles includes protective clothing (e.g. fire fighters' suits, bulletproof vests, gloves), sportswear, home textiles (e.g. blankets, mattresses), medical and hygiene applications (e.g. bandages, surgical apparel, beddings) thermal insulation clothing, casual apparel, footwear, automotive textiles…*etc.* [3, 5]. PCMs are divided into two main groups; paraffin (alkane) and fatty acids. In the field of textiles, paraffinic

hydrocarbons are commonly used due to their outstanding properties such as non-corrosiveness, chemical and thermal stability, non-toxic, low cost and low or non-supercooling [9, 10]. A lot of PCMs are available in the market such as Eicosane, Octadecane, Nonadecane, Heptadecane and Hexadecane, they have different freezing and melting points and when combined in a microcapsule, they store and emit heat energy, and maintain temperature range from 30-34˚C, which is comfortable to the body. Octadecane ($C_{18}H_{38}$) is one of the commonly studied PCM due to its thermos-physical properties, as it has a melting temperature close to the ambient conditions, a translucent liquid phase, and cycle stability [11]. Numerous studies had attempted to study the use of Octadecane in textiles [12-21]

The thermo-physiological properties of textiles are highly affected by many fibres, yarn and fabric structural parameters [22]. Cotton fibres are characterized by their outstanding properties such as high absorbency, biodegradability, drape, easily stylized, heat resistance, high wet strength, softness [23]. Polyester fibre is the most important fibre globally in terms of production volume due to its ease of processing, excellent performance, and low cost [24]. As well, cotton/polyester is the common blended material, it is called poly-cotton and has many unique properties compared to both cotton and polyester fibres such as high strength, softer, low cost and has a wide range of uses.

The objective of this work is to characterize the thermal, physical and mechanical properties of different yarn materials namely; cotton G94, cotton G86, cotton G86/polyester and polyester fibres. The yarns were treated and coated with PCM composite materials Octadecane loaded on Pectin stearate and/or Alginate stearate to enhance the yarns with thermoregulation property. This study is concerned with comparing the thermal behaviour of two common grades of Egyptian cotton fibres (cotton G94 and cotton G86) in addition to polyester fibres that are widely used in industry to present an expanded vision of the behaviour of these materials after treatment with different PCM composites. These smart yarns can be used in producing woven or knitted fabrics for various textile applications such as garments, bedding, insulation, medical uses…*etc.*

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2. Experimental

2.1. Materials

2.1.1. Yarn Materials

In this study, four types of yarn materials were used namely; Cotton Giza 86, Cotton Giza 94, Cotton G86/Polyester (35:65%) and Polyester. They were treated with phase change materials to evaluate their functional performance. The difference between the Egyptian cotton grades G86 and G94 properties is presented in **Error! Reference source not found.**. **[25]** The specifications of the yarn samples produced are listed in **Error! Reference source not found.**.

2.1.2. Chemicals

Pectin (30,000–100,000) and sodium alginate medium molecular weight were purchased from Fluka. Stearic acid, sodium lauryl sulphate, dichloromethane (DCM), dicyclohexylcarbodiimide (DCC), potassium carbonate (K_2CO_3), and Octadecane were purchased from Sigma-Aldrich.

2.2. Methods

2.2.1. Synthesis of fatty acid anhydrides

In an ice-water bath under an argon environment, 10 mmol stearic acid was dissolved in 2 mL dichloromethane and vigorously stirred. In dichloromethane, 5 mmol dicyclohexyl carbodiimide (DCC) was dissolved. The mixture was then added to the soluble DCC and stirred for another 2 hours at an ice bath temperature. Filtration separated the precipitate from the solvent, which was then evaporated from the filtrate in a vacuum to yield the anhydride **[18, 19]**.

2.2.2. Synthesis of pectin-fatty acid esters or alginate-fatty acid esters

The following general esterification technique was used: Using an agate mortar, 10 g pectin or alginate, 10 g anhydride, and (0.1 eq. DCC) (Scheme 1) were ground. The mixture was cooked for 15–25 minutes at 140°C in an oil bath. The mixture was then cooled to room temperature and washed with chloroform. The obtained ester was dissolved in water with the pH set to neutral. The resulting solution was dialyzed for one day in deionized water and then lyophilized for two days **[18, 19]**.

2.2.3. Synthesis of PCM composite based on pectin-fatty acid ester

According to our earlier work **[16, 17, 21]**, PCMs composites were made as follows: by combining pectin or alginate/stearic acid ester with paraffin compounds (n-octadecane; (C18)) at a molar ratio of 1:2 for 14 hours at 110°C. The PCM composite was then used for additional analysis and application.

2.2.4. Application of PCM Composite Matrix on Different Yarns

10 g of PCM composite matrix was transferred to a round flask, then 990 ml water was added and sonicated at 50°C for 10 minutes, then 5 g/L butane tetracarboxylic acid (BTCA) and 5 g/L sodium hypophosphite (SHP) were gradually added and stirred for an additional 15 minutes, according to a modified method from our previous work **[16, 17]**. At 40–50°C, the yarns were submerged in the coating dispersion solution. Coated yarns were dried at 60°C for 5 minutes, then fixed at 130°C for another 5 minutes before being conditioned for the next 24 hours. **Table 3** shows a description of the yarn samples before and after coating with the PCM composite materials. The samples were washed after treating the fabrics to remove the unreacted materials using non-ionic detergent at 50°C for 15 min.

The actual incorporation (%) of the PCM materials transferred to the samples was determined by weighing the coated and untreated fibres.

$$\text{Pickup (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad \textbf{(Eq.1)}$$

Where; W_1 is the dry yarn weight before padding, and W_2 is the weight of coated yarn after drying.

Table 1: Difference between Egyptian cotton grades

Cotton grade	Brightness RD (%)	Yellowness (+b)	Micronaire	Maturity ratio (%)	Fibre length (mm)	Strength (g/Tex)	Elongation (%)	Fibre perimeter (μ)
Giza 86	75.9	8.4	4.5	0.96	33.6	45.1	7.3	47.5
Giza 94	79.1	8.0	4.3	0.94	34.5	43.6	7.4	46.7

Table 2: Specifications of different yarn materials

Yarn Materials	Yarns Properties					
	Yarn Count (Ne)	Twists Coefficient	Tenacity (cN/Tex)	Elongation (%)	U%	CV%
Cotton G 94	30/1	3.41	19.388	5.20	10	12.5
Cotton G 86	60/1	3.8	18.632	4.37	11.54	14.43
Cotton G86/ polyester (35:65) %	60/1	3.8	18.18	6.49	13.53	16.91
Polyester*	70/1	-	32.398	19.946	2.73	3.41

***Note:** Polyester yarn is a continuous welded filament (5 welds/inch),* **U:** *Unevenness,* **CV:** *Coefficient of mass Variation.*
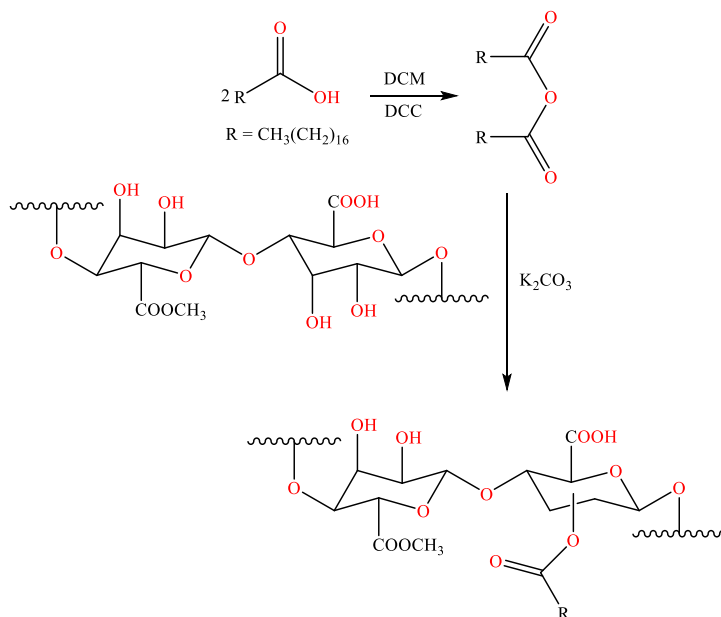
Scheme 1: Preparation of pectin or alginate/stearic acid composites

Table 3: Description of the yarn samples

Sample Code	Description
Y1/B	Cotton Giza 94 without treatment (Blank)
Y1/P	Cotton Giza 94 treated with Octadecane loaded on pectin stearate
Y1/S	Cotton Giza 94 treated with Octadecane loaded on alginate stearate
Y1/PS	Cotton Giza 94 treated with Octadecane loaded on pectin stearate and alginate stearate
Y2/B	Cotton Giza 86 without treatment (Blank)
Y2/P	Cotton Giza 86 treated with Octadecane loaded on pectin stearate
Y2/S	Cotton Giza 86 treated with Octadecane loaded on alginate stearate

Sample Code	Description
Y2/PS	Cotton Giza 86 treated with Octadecane loaded on pectin stearate and alginate stearate
Y3/B	Cotton /polyester without treatment (Blank)
Y3/P	Cotton/polyester treated with Octadecane loaded on pectin stearate
Y3/S	Cotton/polyester treated with Octadecane loaded on alginate stearate
Y3/PS	Cotton/polyester treated with Octadecane loaded on pectin stearate and alginate stearate
Y4/B	Polyester without treatment (Blank)
Y4/P	Polyester treated with Octadecane loaded on pectin stearate
Y4/S	Polyester treated with Octadecane loaded on alginate stearate
Y4/PS	Polyester treated with Octadecane loaded on pectin stearate and alginate stearate

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2.3. Testing and Analysis

2.3.1. Fourier Transform Infrared Spectroscopy (FTIR)

To analyse the chemical alterations and interaction phases in the blank and treated yarn samples, Fourier Transform Infrared Spectroscopy (FTIR) analysis was used to characterise the prepared phase change materials and their composites. The FTIR spectrum was determined using the ATR technique on an FTIR spectrometer model (JASCO FT-IR-6100) with a spectral range of 4000-400 cm^{-1}.

2.3.2. Differential Scanning Calorimetry (DSC)

The difference in the amount of heat required to raise the temperature of a sample and a reference material measured as a function of temperature using DSC [26]. The DSC analysis was carried out using a DSC131 evo differential scanning calorimeter (SETARAM Inc., France). The standards were used to calibrate the instrument (Mercury, Indium, Tin, Lead, Zinc and Aluminium). The purge gases utilised were nitrogen and helium. The test included a heating zone with a temperature range of 25 to 100°C and a heating rate of 10°C/min. The samples were weighed in a 120 ul Aluminium crucible before being sent to the DSC. The thermogram data was analysed using (CALISTO Data processing software v.149).

2.3.3. Duration Index (DI) and Total Resistance to Dry Heat Transfer

The duration index (DI) is a metric that describes the material and the temperature that it is designed to work. It is calculated using equation 2 [27] to determine how long the PCM will remain at a steady temperature during the phase change.

$$\text{DI (J/cm}^3\text{K)} = \frac{\Delta H \times \rho}{\Delta T} \quad \textbf{(Eq. 2)}$$

Where; ΔH is the enthalpy of PCM change of state, ρ is the PCM density, and ΔT is the temperature difference between measured and interest temperatures (ambient (melt or keeping), or body temperature).

The insulation value of clothing systems is the overall resistance to dry heat transfer (R), which is connected to the textile material on which PCM is placed and is calculated using equation 3:

$$\text{R (clo)} = \frac{\Delta T \times A}{H} \quad \textbf{(Eq. 3)}$$

Where; A is the material's area, ΔT is the temperature differential between the two sides of the material, $\Delta T = TF - TR$ (F is the material's face, and R is the material's back), and heat flow (H). The value for textiles is expressed in "clo" (m^2°C/W), a measure for garment insulation derived from sanitary comfort tests. 1clo = 0.155 m^2°C/W, which is the unit for clothing insulation developed from the research of hygienic comfort (zero clo equates to a nude person and 1 clo corresponds to a person wearing a normal business suit). [28, 29]

2.3.4. Scanning Electron Microscope (SEM)

SEM analysis was used to investigate the morphological features of the yarn samples. The experiment was carried out utilizing a Philips XL30 scanning electron microscope with a LaB6 electron gun and a Philips-EDAX/DX4 electron detector. Using a 30kV accelerating voltage, the samples were scanned at various magnifications depending on the clarity of the pictures to analyse the surface morphology. To record pictures, samples were glued using carbon glue and metalized with gold vapour deposition.

2.3.5. Characterization of the Physio-mechanical Properties of Yarns

All yarn samples were examined for their physical and mechanical characteristics before and after treatment with PCM composites. According to ISO-139 [30], the samples were exposed to typical atmospheric conditions for 24 hours before being tested. The following tests were performed on the yarn samples: yarn count according to ASTM-D 1059 [31]. The Uster Tensorapid Tester-Japan was used to assess tenacity and elongation following ASTM-D 2256 [32]. Evenness analysis was carried out to determine the number of thick places, thin places, neps, U% and also the CV% was calculated according to equation 4. The test was done using Uster tester 1-model B spectrograph-Japan according to ASTM-D 1425 [33].

$$\text{CV\%} = \text{U\%} \times 1.25 \quad \textbf{(Eq. 4)}$$

2.3.6. Statistical Analysis of Results

The tests results were statistically analysed using Analysis of Variance (ANOVA), the significance level was set at $P \leq 0.05$. The least Significant Difference (LSD) was carried out to obtain the least significant differences between different yarn properties after treatment with the PCM composites.

3. Results and Discussion

3.1. Characterization of pectin/alginate – stearic acid (Hosting materials)

3.1.1. FT-IR analysis

FT-IR was used to characterise pectin stearate and alginate stearate. **Error! Reference source not found.** shows the IR spectra of pectin, alginate, stearic acid anhydride, pectin stearate, and alginate stearate. Peaks at 3402, 2932 cm^{-1} in the FT-IR spectra of pectin and alginate correspond to –OH and –CH stretching peaks. Furthermore, two further peaks at 1454 and 1357 cm^{-1} were ascribed to CH$_2$ and –OH peaks, respectively. **Error! Reference source not found.** also showed

stearic acid anhydride, which was used to chemically modify pectin or alginate. The chemical change is reflected in the IR spectra as follows: For pectin stearate, 3442 cm^{-1} for O–H, 2923 and 2849 cm^{-1} for C–H, 1729 cm^{-1} for C=O (methyl ester), 1707 cm^{-1} for C=O (fatty acid ester), 1632 and 1431 cm^{-1} for COO, 1201 and 1128 cm^{-1} for C–O; for alginate stearate, 3438 cm^{-1} for O–H, 2915 and 2842 cm^{-1} for C–H, 1747 cm^{-1} for C=O (methyl ester), 1694 cm^{-1} for C=O (fatty acid ester), 1627 and 1433 cm^{-1} for COO−, 1204 and 1147 cm^{-1} for C–O.
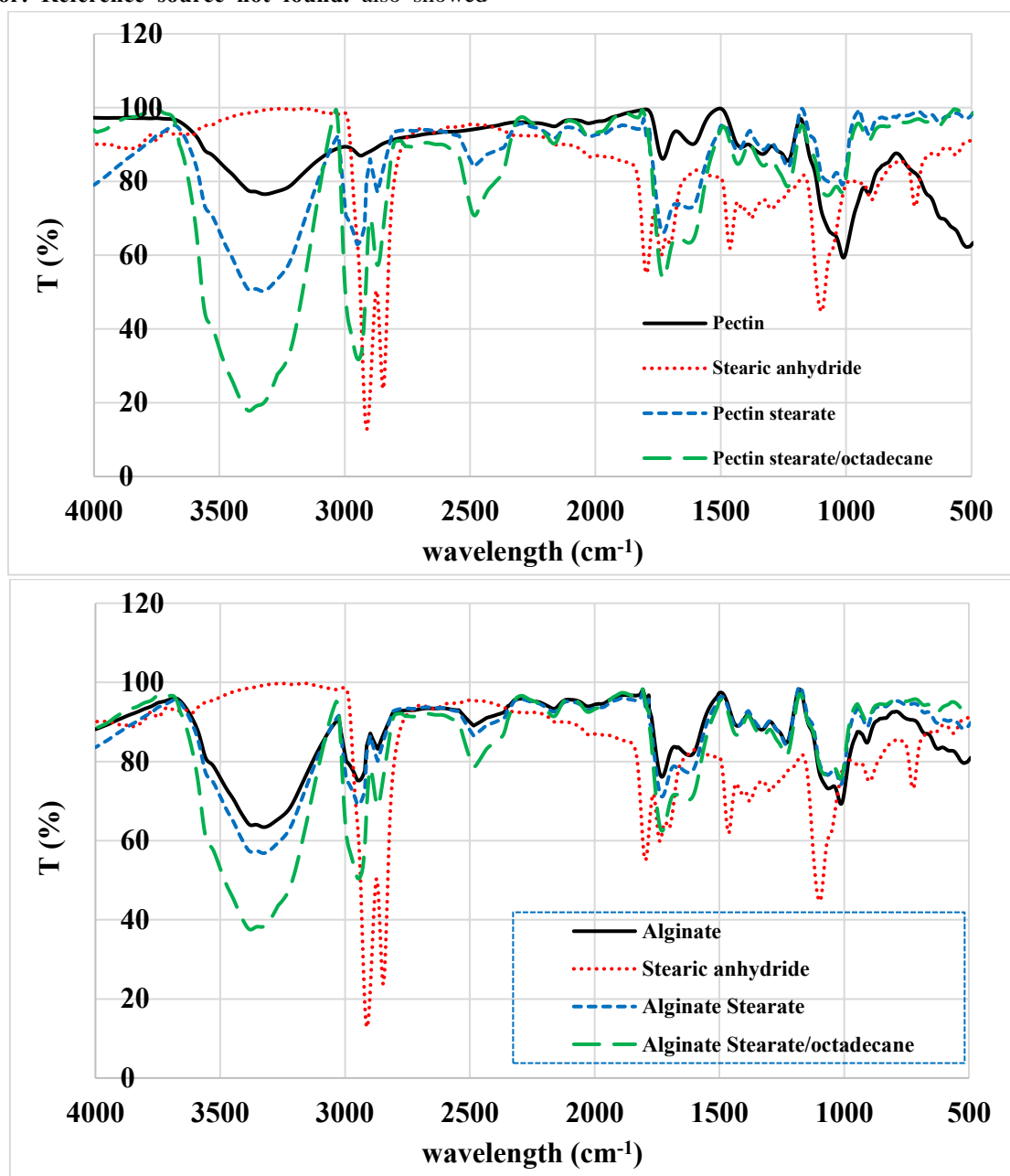
Figure 1: FT-IR spectra of hosting materials with/without Octadecane

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3.1.2. DSC Analysis

DSC values T_o (°C), T_p (°C), and ΔH (J/g) for pectin, alginate, stearic acid, Octadecane (PCM material), and prepared composites with and without Octadecane composite were collected and listed in Error! Reference source not found..

The peak of 137.1(°C) in the DSC data for pectin is equal to the reported values for pure pectin keeping/peak temperature (Tp) [18].

The inclusion of alginate in the final composite form causes an increase in the latent heat of hosting materials greater than pectin, as seen in Error! Reference source not found. and **Error! Reference source not found.**.

Also, once the biopolymer reacted with stearic acid, its melting temperature dropped, and it dropped much more after adding Octadecane. The ultimate melting temperature was appropriate for phase transition materials to textile materials, and hence for the human body. In addition, the DI values of the Octadecane-produced composites suggest that the optimal composite with the greatest DI may be arranged as follows: Alginate stearate/ Pectin stearate/ Octadecane (III*) > Alginate stearate/Octadecane (II*) > Pectin stearate/ Octadecane (I*).

Table 4: DSC data for hosting materials with/without Octadecane from 2nd heating **[21]**

| Hosting Materials	T_o	T_p	DH	DI * (J/cm^{3}K)
Pectin [18]	135.7	137.1	32.12	-
Alginate [34]	251.1	288.32	43.24	-
Stearic acid [17]	65.2	69.7	166.52	-
Octadecane [16]	29.3	33.4	241.44	-
Pectin Stearate (I)	30.16	35.17	53.29	6.23
Alginate Stearate (II)	30.14	36.11	57.92	6.75
I + II (III)	30.13	37.69	62.31	7.26
Pectin Stearate/Octadecane (I*)	32.19	40.19	112.34	18.68
Alginate Stearate/Octadecane (II*)	32.67	42.69	188.57	34.84
I* + II* (III*)	32.42	40.19	255.58	44.64
* **Duration index**: based on ΔT from melt point to body temperature (37°C) and average density of 0.8 g/cm^3				
T_o: Onset/melt Temperature, **Tp**: Keeping Temperature, **ΔH**: Enthalpy				
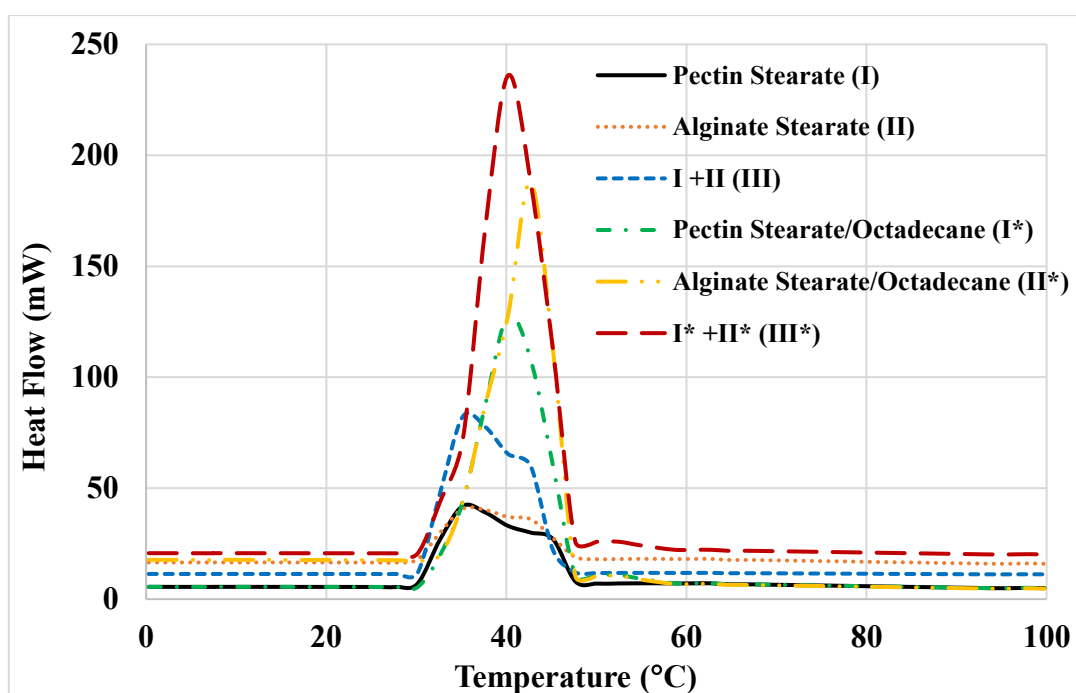
Figure 2: DSC curves for hosting materials with/without Octadecane from 2nd heating

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3.2. Characterisation of Different Yarn Materials Thermal Properties

Heat loss to the external environment occurs mostly by convection, radiation, and evaporation from the skin, as well as latent heat of perspiration; however, textile gear provides warmth imperviousness to heat flow. Different types of yarn materials, Cotton Giza 94 and Giza 86, Polyester, and Cotton Giza 86/polyester blend, were covered by the created PCM composite materials to be further employed in the production of different types of textiles **[29, 35-38].**

The DSC findings of each yarn samples coated with pectin or alginate/stearic acid with Octadecane are shown in Error! Reference source not found. and **Error! Reference source not found.**. When compared to uncoated yarns, the yarns coated with

these PCM composites imparted the thermo-regulating characteristic with greater latent heat and DI. Furthermore, coated yarns with pectin/alginate/stearic as hosting materials give greater latent heat and DI than covered yarns with pectin/stearic and alginate/stearic. In addition, overall resistance to dry heat transfer was determined, confirming that yarns coated with pectin/alginate/stearic acid/octadecane composite were more comfortable than yarns coated with other composites. Finally, it can be concluded that all the studied yarns can be coated with PCM composites and that the coated yarn outperforms the uncoated yarn. For coated yarns, the latent heat stored is in the following order: Cotton G86/polyester > Polyester > Cotton G86 > Cotton G 94.
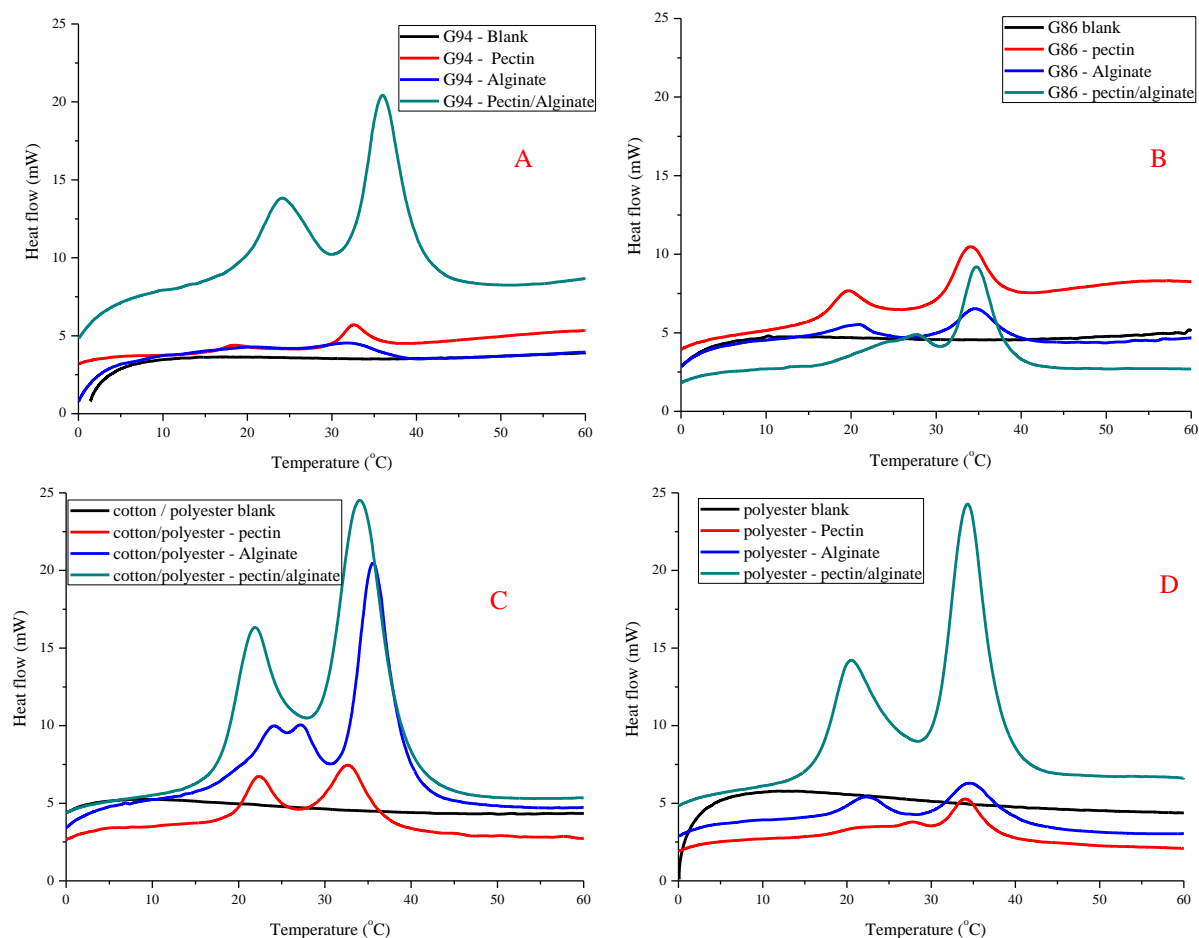

Figure 3: DSC curves for covered yarns with pectin or alginate/stearic acid and Octadecane at 2nd heating
a) Cotton G94, b) Cotton G86, c) Cotton G86/polyester, and d) Polyester

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Table 5: DSC, Duration index and Total Resistance results of different yarns covered with PCM composite materials

Treated Fabrics	To (°C)	Tp (°C)	ΔH (J/g)	DI * (J/cm³K)	R ** (clo)
G94 - Blank	6.1	10	0.061	0.00	0.159836
G94 - Pectin	12.85	32.574	8.468	0.28	0.005823
G94 - Alginate	11.16	32.256	12.778	0.40	0.004127
G94 - Pectin/Alginate	17.14	36.02	44.97	1.81	0.00105
G86 - Blank	6.1	10	0.056	0.00	0.174107
G86 - Pectin	13.71	33.97	19.154	0.66	0.002644
G86 - Alginate	12.58	34.574	21.24	0.70	0.002589
G86 - Pectin/Alginate	17.77	34.81	41.645	1.73	0.001023
Cotton G86/Polyester - Blank	5.05	7.21	0.049	0.00	0.110204
Cotton G86/Polyester - Pectin	15.58	32.664	54.014	2.02	0.000791
Cotton G86/Polyester - Alginate	15.21	38.87	79.931	2.93	0.00074
Cotton G86/Polyester - Pectin/Alginate	15.59	34.07	100.07	3.74	0.000462
Polyester - Blank	36.5	36.9	0.07	0.11	0.014286
Polyester - Pectin	17.33	34.16	23.707	0.96	0.001775
Polyester - Alginate	13.21	34.627	34.05	1.15	0.001572
Polyester - Pectin/Alginate	12.98	34.352	71.873	2.39	0.000743

* Duration index: based on ΔT from melt point to keeping temperature and average density of 0.8 g/cm³

**R: Total Resistance to Dry Heat Transfer

T_o: Onset/melt Temperature, **Tp**: Keeping Temperature, **ΔH**: Enthalpy

3.3. Scanning Electron Microscope (SEM)

Error! Reference source not found. **(A-D)** shows the SEM of different yarn samples including the blank samples (Y1, Y2, Y3 and Y4), and the samples treated with Octadecane as PCM material loaded on three composite materials; Pectin Stearate/Octadecane (Y1/P, Y2/P, Y3/P and Y4/P), Alginate Stearate/Octadecane (Y1/S, Y2/S, Y3/S and Y4/S) and Pectin Stearate/Alginate Stearate/Octadecane (Y1/PS, Y2/PS, Y3/PS and Y4/PS). **Error! Reference source not found.** shows the high deposition of the prepared PCM composites materials on the surfaces of different yarn materials compared to blank samples. Also, it was observed that deposition of Pectin Stearate/Octadecane composite material on yarn samples (Y1/P, Y2/P, Y3/P and Y4/P) is higher compared to the other treated yarn samples. This could be attributed to the thickening of pectin material **[39]**. Treatment of yarn samples with Pectin Stearate/Alginate Stearate/Octadecane composite matrix (Y1/PS, Y2/PS, Y3/PS and Y4/PS) showed a uniform and smooth distribution on the surface of all types of treated yarns.

3.4. Physical and Mechanical Properties of Yarns
3.4.1. Yarns Count Changes

The influence of the PCM treatment materials on yarns count and weight is illustrated in **Error! Reference source not found.** and **Error! Reference source not found.**. It was found that the treatment of cotton G86 yarn samples with the PCM materials composites highly increased the weight of the yarn samples along their lengths, especially the sample treated with Pectin Stearate/Octadecane, followed by the sample treated with Pectin Stearate/Alginate Stearate/Octadecane. This could be attributed to cotton G86 yarn count 60/1 Ne which is characterized by its low thickness compared to the other cotton samples, and also to the properties of the cotton fibres listed in **Error! Reference source not found.**. Since cotton fibre structure is characterized by natural twists found at regular intervals along its length. The twists also called convolutions which give cotton an uneven surface which increase the inter fibres friction and affect the amount of treatment materials deposited and coated the fibres' surfaces **[40]**.
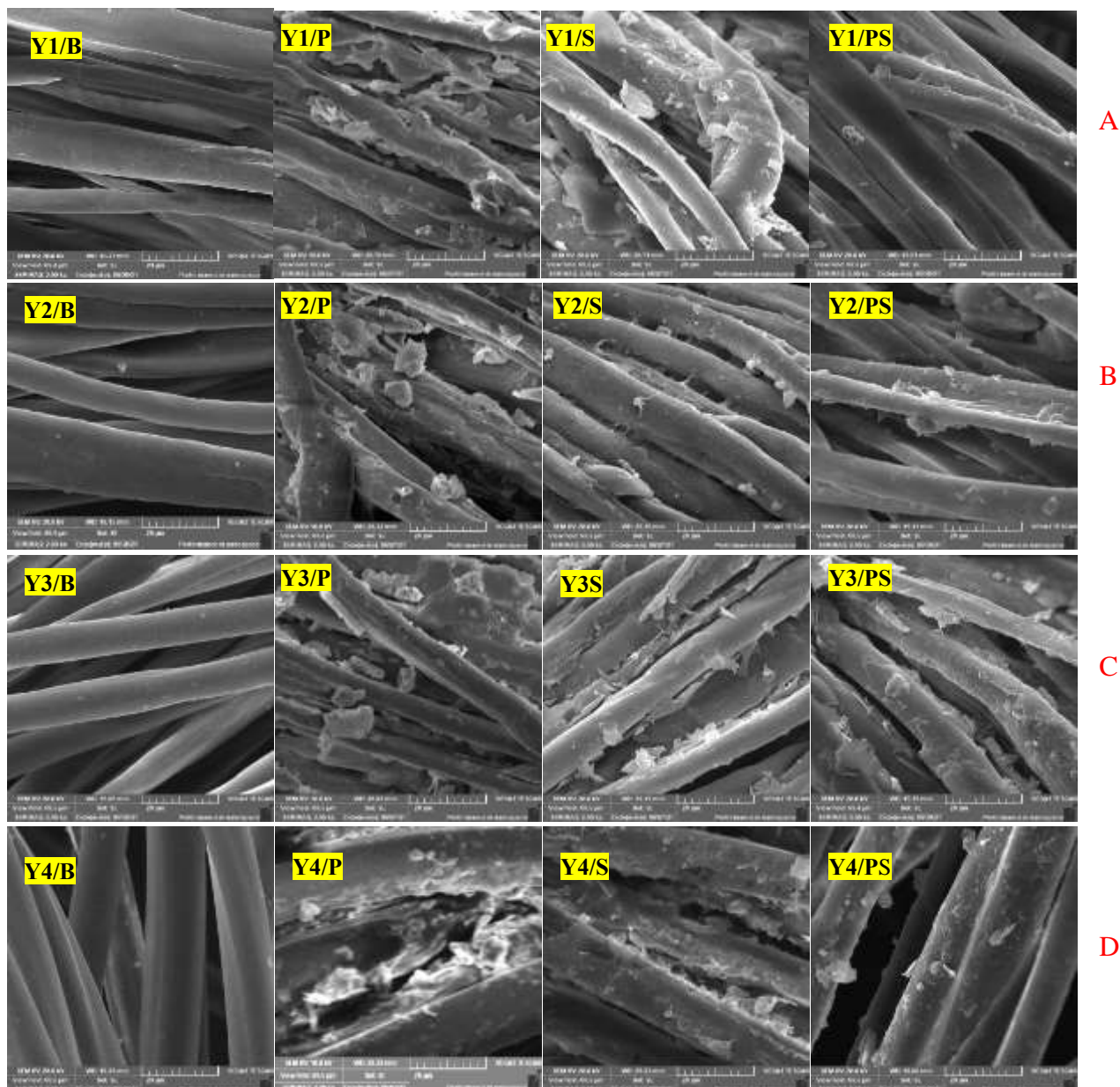
Figure 4: SEM of different yarn materials after applying PCMs treatments
(A) Cotton G 94, (B) Cotton G 86, (C) Cotton G86 /Polyester and (D) Polyester

Also, it was observed that the yarn samples treated with Pectin Stearate/Alginate Stearate/Octadecane showed higher values of increase in weight (Add on %), this could be related to the uniform deposition of octadecane loaded on pectin stearate and alginate stearate materials on the yarns' surfaces. Cotton G94 yarn samples showed low count changes after treatment, this may be related to G94 yarn count 30/1 Ne and its high thickness which led to reducing the amount of treatment materials deposited and adsorbed on the yarns' surfaces along their lengths. Moreover, polyester samples showed the lowest increase in weight after treatment, due to the nature of polyester

fibre and its uniform cross-section.

3.4.2. Yarns Tenacity and Elongation

Error! Reference source not found.A shows the results of the tenacity test carried out on yarn samples after treatment with the PCM composite materials. It was observed from **Error! Reference source not found.** that the blank polyester yarn showed the highest tenacity of 32.4 cN/Tex due to its high strength compared to the other samples. After treatment as shown in **Error! Reference source not found.A**, it was found that for Cotton G94 samples and Cotton G86 samples especially the sample Y2/P, the tenacity

of yarns increased after all treatments. This could be related to the high absorption of the treatment materials on the cotton yarns surfaces, which strengthen the fibres to bear the tensile load. Also, it was found for the blended cotton/polyester yarns and polyester yarns, that the samples Y3/S, Y3/PS, Y4/S and Y4/PS showed increased tenacity values after treatment. This could be related to the effect of alginate stearate material during treatments. While samples Y3/P and Y4/P showed lower tenacity values after the treatment caused by the high gelling and viscosity of pectin stearate material.

Table 6: Add on (%) in weight of different yarn materials after treatment and the imperfections of yarn samples/100m

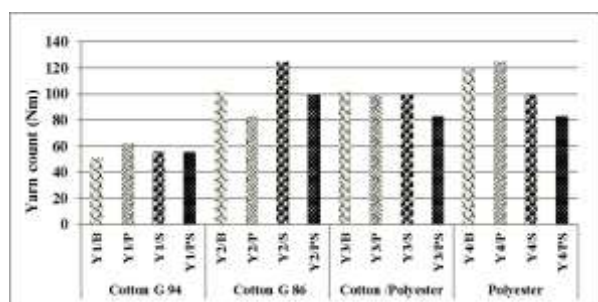| Sample Code	Add on (%)	Yarn Imperfections/100 m		
		Thin places	Thick places	Neps
Y1/B	0	0	0	2
Y1/P	60	6	0	2
Y1/S	80	0	0	2
Y1/PS	80	0	4	4
Y2/B	0	6	2	4
Y2/P	500	12	6	8
Y2/S	300	12	2	8
Y2/PS	400	12	2	22
Y3/B	0	6	10	4
Y3/P	66.7	8	18	2
Y3/S	66.7	18	18	4
Y3/PS	100	52	30	37
Y4/B	0	0	0	0
Y4/P	25	0	0	0
Y4/S	25	0	0	0
Y4/PS	50	2	4	6

Figure 5: Effect of different treatments on yarn count

Error! Reference source not found.B displays the results of the elongation % of yarn samples after treatment with the PCM materials. From Error! Reference source not found., it was noted that the

polyester yarn samples have the highest elongation of 20% compared to all samples. After treatments, the elongation % of Cotton G94, Cotton G86 and Cotton/polyester yarn samples decreased. This could be related to the high thickening and gelling nature of the PCM composite materials used **[39, 41]**. Also, the strength properties of cellulosic materials increase with the wetness and impregnation of different treatment materials, and therefore their elongation decreased, as the properties of strength and elongation have an indirect relationship. Additionally, cotton G86 samples showed lower elongation values compared to cotton G94 and cotton/polyester samples. It was found also that the polyester samples elongation % increased after treatment showing the highest elongation values, due to the high elongation properties of polyester compared to cotton fibres.
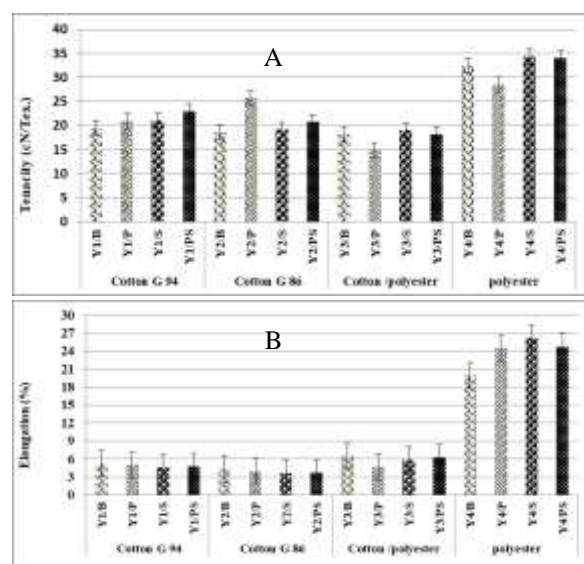

Figure 6: Effect of different treatments on
A) Tenacity and B) Elongation

3.4.3. Evenness Test Results

Error! Reference source not found. shows the results of the evenness test applied on the blank and treated yarn samples. It was indicated that the polyester yarn samples recorded the lowest imperfections in terms of thin and thick places and neps compared to all samples. This could be related to the long fibres, high smooth and uniform cross-section of polyester fibres, which leads to low variations across its length **[42]**.

Cotton G94 yarn samples showed the lowest number of imperfections compared to cotton G86 samples. This could be related to the long fibre length and high thickness compared to G86 (**Error!**

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Reference source not found.) which may affect reducing the number of protruding fibres on its surface. Moreover, it was found that the cotton/polyester samples showed the highest imperfections after treatment compared to all samples. This may be attributed to the presence of short and immature cotton fibres in the blend, which increased the number of imperfections, also due to the deposition of the treatment materials on the yarn's surfaces. The yarn samples treated with Octadecane/Pectin stearate/Alginate stearate namely Y1/PS, Y2/PS, Y3/PS and Y4/PS showed a higher number of imperfections compared to the other yarn samples treated with Pectin stearate and Alginate stearate separately. This could be related to the deposition of both materials and agglomeration on the yarn's surfaces, which lead to the presence of imperfections on yarns.

Error! Reference source not found.(A and B) shows the unevenness (U%) and coefficient of mass variation (CV%) of the yarn samples after treatment with PCM materials. The results indicated that the unevenness % of cotton G86, cotton/polyester and polyester yarn samples increased after treatment, due to the increase and variation in yarns thickness caused by the deposition of treatment materials on their surfaces. Cotton G94 samples Y1/S and Y1/PS showed lower unevenness values, which may be related to lower absorption of treatment material on their surfaces. Also, it was found that the cotton/polyester samples recorded the highest U% and CV% values followed by cotton G86 samples, while polyester samples showed the lowest U% and CV% values. This could be attributed to the low variations in polyester yarn diameter.
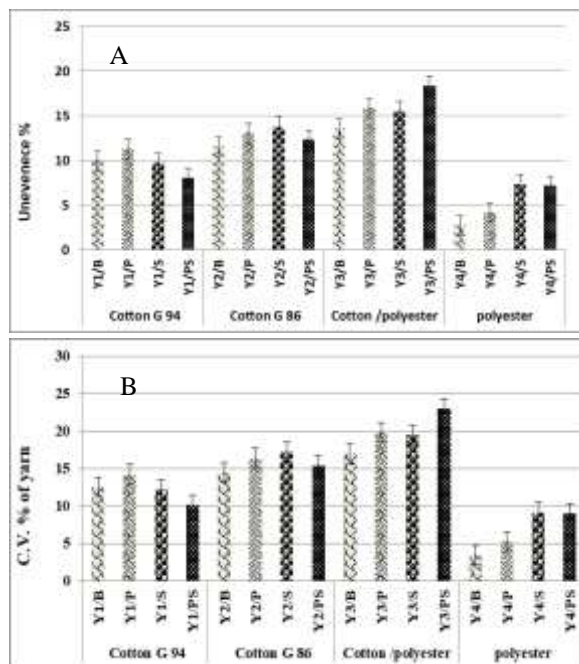

Figure 7: Effect of different treatments
(A) Unevenness and (B) Coefficient of mass variation

3.5. Study of the Significant Effect of PCM Treatment Materials on Yarns Properties

Error! Reference source not found. assigns to the significant effect of different treatments using various PCM composite materials on the Cotton G94 (Y1) yarn sample. It was noted that tested yarn properties were highly significantly affected after treatment except yarn elongation. In the same context, LSD values were calculated (According to the ANOVA test) to determine the effective differences of treatments within affected properties, as it ranges between (0.52-1.84).

Moreover, Error! Reference source not found. demonstrates the LSD values, as well as the significant differences of treatments at a single test. The findings showed that there is a change in the behaviour of the Cotton G94 sample after treatments as follows:

Tenacity: (Y1/PS) treated samples vary greatly with other samples, indicating a substantial difference between treatments. While on the other hand, there are not any significant differences between blank samples (Y1/B) and Y1/P, Y1/S treated samples on tenacity property.

Yarn Unevenness (U%): All samples accomplish quite different from each other, which clarify that the treatments obtain a great effect on yarn evenness.

Coefficient of mass Variation (CV%): The findings show that all samples achieve scores higher than calculated LSD, except for the blank and Y1/S treated samples, signifying those treatments have a

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varied influence on yarn CV%.

Table 8 presents the effectiveness of different treatments utilizing various PCM composite materials on the Cotton G86 (Y2) yarn sample. It was shown that tenacity and elongation properties were quite significantly affected after treatment except for unevenness and coefficient of mass variation. In addition, to illustrate the significant differences between treatments, LSD values were calculated, as it ranges among (0.41-1.97).

Also, **Table 8** demonstrates the LSD values of the effect of the significant treatment, according to the ANOVA test, as well as the differences between samples at a single test. The findings show that there is a change in the behaviour of the Cotton G86 sample

Table 10 points to the significant effect of different treatments using various PCM composite materials on polyester (Y4) yarn samples. It was noted that all the yarn properties were high significantly affected after

Table 10 demonstrates also the LSD values of the significant effect according to the ANOVA test, as well as the differences between samples at a single test. The findings show that there is a change in the behaviour of polyester samples after treatments as follows:

Tenacity: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/P differ in behaviour and values with

Table 9 points to the significant effect of multiple treatments utilizing various PCM composite materials on a Cotton G86/polyester (Y3) yarn sample. The results showed that yarn properties were dramatically modified following treatment, with the elongation

after treatments as follows:

Tenacity: The results assign that blank sample tenacity (Y2/B) significantly differs from the treated samples (Y2/P) and (Y2/PS) only. The treated sample (Y2/P) executes a considerable modification on the tenacity property, where its differences with other samples exceed LSD value. Moreover, there is not any magnitude effect between (Y2/S) and (Y2/PS) treated samples.

Elongation: The resulting shows that the elongation effectively changed between blank sample (Y2/B), and treated samples (Y2/S) and (Y2/PS) only. There are no any critical differences in elongation behaviour between the treated samples.

treatment. In the same context, LSD was calculated to determine the significant differences between treatments and their effect on yarn properties, as it ranges between (0.69-1.34).
Y4/S and Y4/PS samples. This clarifies that the treatments obtained a great effect on yarn tenacity.

Elongation: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/S differs in behaviour and values with Y4/P and Y4/PS sample, while there is not any variation among Y4/P and Y4/PS samples.

property having the greatest impact compared to other qualities. LSD was calculated in the same context to identify the substantial variations between treatments and their effect on yarn properties, as it varies between (0.65-3.85).

Table 7: Significant effect of PCM treatment on Cotton G94 yarn (Y1) properties and its LSD analysis

(Y1) Properties	P-value	Significance	LSD	Differences				
					Y1/B	Y1/P	Y1/S	Y1/PS
Tenacity	0.0069	**	1.839	Y1/B	0	1.50	1.61	3.60
				Y1/P	1.50	0	0.10	2.10
				Y1/S	1.61	0.10	0	1.99
				Y1/PS	3.60	2.10	1.99	0
Yarn Unevenness (U %)	4.62E-06	**	0.5182		Y1/B	Y1/P	Y1/S	Y1/PS
				Y1/B	0	1.72	0.1	1.50
				Y1/P	1.72	0	1.62	3.23
				Y1/S	1	1.62	0	1.60
				Y1/PS	1.50	3.23	1.60	0
Coefficient of mass Variation (CV%)	4.62E-06	**	0.6478		Y1/B	Y1/P	Y1/S	Y1/PS
				Y1/B	0	2.15	0.125	1.88

					Y1/B	Y1/P	Y1/S	Y1/PS
				Y1/P	2.15	0	2.03	4.04
				Y1/S	0.125	2.03	0	2.00
				Y1/PS	1.88	4.04	2.00	0
Elongation	0.162317	NS	-	-	-	-	-	-

** Highly Significant   * Significant   **NS:** Non-significant
Note: shaded areas in the table refer to significant differences in treatments.

Table 8: Significant effect of PCM treatment on Cotton G86 yarn (Y2) properties and its LSD analysis

(Y2) Properties	P-value	Significance	LSD	Differences				
					Y1/B	Y1/P	Y1/S	Y1/PS
Tenacity	3.69E-06	**	1.9732	Y1/B	0	7.07	0.53	2.13
				Y1/P	7.07	0	6.53	4.94
				Y1/S	0.534	6.53	0	1.596
				Y1/PS	2.13	4.94	1.59	0
Elongation	0.006491	**	0.4124		Y1/B	Y1/P	Y1/S	Y1/PS
				Y1/B	0	0.38	0.73	0.67
				Y1/P	0.38	0	0.348	0.29
				Y1/S	0.73	0.34	0	0.056
				Y1/PS	0.67	0.29	0.056	0
Yarn Unevenness (U %)	0.077149	NS		-	-	-	-	-
Coefficient of mass Variation (CV%)	0.077149	NS		-	-	-	-	-

** Highly Significant   * Significant   **NS:** Non-significant
Note: shaded areas in the table refer to significant differences in treatments.

Table 10 points to the significant effect of different treatments using various PCM composite materials on polyester (Y4) yarn samples. It was noted that all the yarn properties were high significantly affected after

Table 10 demonstrates also the LSD values of the significant effect according to the ANOVA test, as well as the differences between samples at a single test. The findings show that there is a change in the behaviour of polyester samples after treatments as follows:

Tenacity: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/P differ in behaviour and values with

Table 9 shows also the LSD values and differences between samples for attributes that are significantly influenced (according to the ANOVA test). The results demonstrate that after treatment, the behaviour of Cotton G94/polyester samples varies as follows:

Tenacity and Elongation: blank samples (Y3/B) highly differ in behaviour with Y3/P sample only, while (Y3/P) treated sample highly differs in behaviour compared with all other samples.

treatment. In the same context, LSD was calculated to determine the significant differences between treatments and their effect on yarn properties, as it ranges between (0.69-1.34).
Y4/S and Y4/PS samples. This clarifies that the treatments obtained a great effect on yarn tenacity.

Elongation: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/S differs in behaviour and values with Y4/P and Y4/PS sample, while there is not any variation among Y4/P and Y4/PS samples.

Yarn Unevenness (U%): blank sample (Y3/B) differs significantly in behaviour with treated sample Y3/PS only, and there is no substantial change in the yarn behaviour between treated samples.

Coefficient of mass Variation (CV%): According to discrepancies across samples, the Y3/PS sample differs considerably in behaviour and values compared with all samples, and there is no significant effect between other samples.

Table 10 points to the significant effect of different treatments using various PCM composite materials on polyester (Y4) yarn samples. It was noted that all the yarn properties were high significantly affected after

Table 10 demonstrates also the LSD values of the significant effect according to the ANOVA test, as well as the differences between samples at a single test. The findings show that there is a change in the behaviour of polyester samples after treatments as follows:

Tenacity: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/P differ in behaviour and values with

treatment. In the same context, LSD was calculated to determine the significant differences between treatments and their effect on yarn properties, as it ranges between (0.69-1.34).

Y4/S and Y4/PS samples. This clarifies that the treatments obtained a great effect on yarn tenacity.

Elongation: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/S differs in behaviour and values with Y4/P and Y4/PS sample, while there is not any variation among Y4/P and Y4/PS samples.

Table 9: Significant effect of PCM treatment on Cotton G86/ polyester yarn (Y3) properties and its LSD analysis

(Y3) Properties	P-value	Significance	LSD	Differences				
					Y1/B	Y1/P	Y1/S	Y1/PS
Tenacity	0.013287	*	2.393	Y1/B	0	3.206	0.794	0.072
				Y1/P	3.206	0	4	3.134
				Y1/S	0.794	4	0	0.866
				Y1/PS	0.072	3.134	0.866	0
					Y1/B	Y1/P	Y1/S	Y1/PS
Elongation	8.6E-05	**	0.6519	Y1/B	0	1.822	0.618	0.168
				Y1/P	1.822	0	1.204	1.654
				Y1/S	0.618	1.204	0	0.45
				Y1/PS	0.168	1.654	0.45	0
					Y1/B	Y1/P	Y1/S	Y1/PS
Yarn Unevenness (U %)	0.047803	*	3.0821	Y1/B	0	2.51	2.31	5
				Y1/P	2.51	0	0.2	2.49
				Y1/S	2.31	0.2	0	2.69
				Y1/PS	5	2.49	2.69	0
					Y1/B	Y1/P	Y1/S	Y1/PS
Coefficient of mass Variation (CV%)	0.047803	*	3.8527	Y1/B	0	3.13	2.88	6.25
				Y1/P	3.13	0	0.25	3.11
				Y1/S	2.88	0.25	0	3.36
				Y1/PS	6.25	3.11	3.36	0
** Highly Significant * Significant **NS:** Non-significant								
Note: shaded areas in the table refer to significant differences in treatments.								

Yarn Unevenness (U%): blank sample (Y4/B) differs in behaviour and values with samples Y4/P, Y4/S and Y4/PS, and the sample Y4/P differs in behaviour and values with Y4/S and Y4/PS samples. This reveals that the treatments had a vital effect on yarn evenness.

Coefficient of mass Variation (CV%): blank

sample (Y4/B) differ in behaviour and values with the samples Y4/P, Y4/S and Y4/PS, also Y4/P sample differs in behaviour and values with the samples Y4/S and Y4/PS, which clarify that the treatments obtained a great effect on the CV of yarn.

Table 10: Significant effect of PCM treatment on polyester yarn (Y4) properties and its LSD analysis

(Y4) Properties	P-value	Significance	LSD	Differences				
					Y1/B	Y1/P	Y1/S	Y1/PS
Tenacity	1.4E-11	**	0.694	Y1/B	0	3.874	2.02	1.646
				Y1/P	3.874	0	5.89	5.52
				Y1/S	2.02	5.89	0	0.374
				Y1/PS	1.646	5.52	0.374	0
Elongation	2.38E-07	**	1.3438		Y1/B	Y1/P	Y1/S	Y1/PS
				Y1/B	0	4.504	6.254	4.696
				Y1/P	4.504	0	1.75	0.192
				Y1/S	6.254	1.75	0	1.558
				Y1/PS	4.696	0.192	1.558	0
Yarn Unevenness (U %)	0.000641	**	1.06056		Y1/B	Y1/P	Y1/S	Y1/PS
				Y1/B	0	1.495	4.615	4.445
				Y1/P	1.495	0	3.12	2.95
				Y1/S	4.615	3.12	0	0.17
				Y1/PS	4.445	2.95	0.17	0
Coefficient of mass Variation (CV%)	0.000641	**	1.3257		Y1/B	Y1/P	Y1/S	Y1/PS
				Y1/B	0	1.86	5.76	5.55
				Y1/P	1.86	0	3.9	3.68
				Y1/S	5.76	3.9	0	0.21
				Y1/PS	5.55	3.68	0.21	0

** Highly Significant   * Significant   **NS:** Non-significant

Note: shaded areas in the table refer to significant differences in treatments.

From

Table 10 points to the significant effect of different treatments using various PCM composite materials on polyester (Y4) yarn samples. It was noted that all the yarn properties were high significantly affected after

Table 10 demonstrates also the LSD values of the significant effect according to the ANOVA test, as well as the differences between samples at a single test. The findings show that there is a change in the behaviour of polyester samples after treatments as follows:

Tenacity: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/P differ in behaviour and values with

Table 10, it is worth mentioning here that there is a significant difference amongst different yarns treatments using various PCM composite materials, which refer to the magnificent impact for these treatments on the properties of Y3 and Y4 (Cotton G86/polyester & Polyester) yarn samples.

4. Conclusion

This work aims to treat yarns from different

treatment. In the same context, LSD was calculated to determine the significant differences between treatments and their effect on yarn properties, as it ranges between (0.69-1.34).

Y4/S and Y4/PS samples. This clarifies that the treatments obtained a great effect on yarn tenacity.

Elongation: blank samples (Y4/B) differ in behaviour and values with Y4/P, Y4/S and Y4/PS samples, and the sample Y4/S differs in behaviour and values with Y4/P and Y4/PS sample, while there is not any variation among Y4/P and Y4/PS samples.

Table 9 and

materials; Cotton G94, Cotton G86, Cotton G86/Polyester and Polyester with PCMs to acquire them thermoregulation property. The yarns were treated with three PCM composites consisting of Octadecane as (PCM material) hosted/loaded on pectin stearate or alginate stearate separately, or loaded on both pectin stearate and alginate stearate together. Characterization of the yarns functional properties was carried out before and after treatment

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with PCM composites. The results are summarized as follows:

- The prepared PCM composite materials showed high heat resistance.
- All the treated yarns coated with the PCM composite materials showed preferable results over blank yarns in terms of higher latent heat, DI and heat resistance, and were arranged as follows; Cotton G86/polyester, Polyester, Cotton G86, and Cotton G94.
- The treated yarns with PCM composite materials achieved a highly-significant effect for most of the physical and mechanical properties especially polyester and cotton G86/polyester yarns.

As a result, the prepared smart yarns treated with PCM composites with thermoregulation properties can be used in producing woven or knitted fabrics for various textile applications such as; garments, bedding, insulation, medical and protective textiles…*etc.*, to provide thermal stability where there is a variation in the ambient temperature.

5. Conflict of interest

We confirm that there is no conflict of interest.

6. Acknowledgement

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