Egypt. J. Chem. **Vol. 66,** No. 6 pp. 187 - 196 (2023)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Devolving Polyester Sportswear Knitted Fabric Using Nanocellulose Fibers from Cotton Linter

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Abstract

Nowadays, the demand for sports products with high performance in increased significantly. Nanotechnology has opened new ways to develop, and to add desirable functions to sportswear. Nanocellulose has emerged as a sustainable and promising nanomaterial owing to its unique structures and superb properties. In this study, researcher prepared nanocellulose from cotton wastes using acid hydrolysis followed by mechanical pulverization and, 37 kHz high power ultrasonic for 300 min. Polyester fabric samples were padded with varying concentrations of nanocellulose suspension (0.1g/l – 0.3g/l and 0.5g/l) with 5g /l surfactant. Samples were dried at 80° and then cured using either oven at 180°C or microwave for 3 min and 60 s. Some mechanical (burst & pilling resistance), anti-bacterial, and fastness tests were done. The best results were achieved with an increase in the concentration of nanocellulose in the aqueous media. The treatments of produced nanocellulose on Polyester fabric improve its antimicrobial and positively influence the mechanical, with good UPF and fastness properties. These results support potential future industrial application of nanocellulose/polyester fabric as ductile, lightweight and cost-effective substitute for sportswear application.

Keywords: Nanotechnology, Nanocellulose, Sportswear, Antimicrobial, Fastness properties.

1. Introduction

Consumers have been asking a smart feature that allows textile materials to respond to and adapt to the surrounding environment beyond just insulating and protecting the body as the textile industry evolves, because today a decent design is not enough for clothing. [1] [2] Sportswear is an essential sector for the creation of new products that perform well and are comfortable. [3] Performance sportswear improves athletes' performance by providing special functionality such as protection from adverse weather conditions such as rain, snow, extreme cold, and heat. [4] The amount of demand for high-performance apparel varies according to gender, age, and activity type. [5]

The following are the most crucial functions required in sportswear:

•Anti-static properties for dissipating electrical charge

•Antimicrobial properties to prevent bacterial growth on the skin.

• UV protection to block harmful UV-A and UV-B radiation. [3]

• Clothing comfort, or the sensation of coolness/warmth, is an essential aspect of sportswear. [6]

• Sportswear should be able to maintain thermal balance between the wearer's surplus heat and the higher metabolic rate. [7] Comfort in sportswear can be divided into four basic types, namely: [8]

1-Thermo-physiological comfort:

Thermo-physiological comfort encompasses fabric thermal properties and sweat absorption. Clothing's moisture transfer behaviour is very important in determining its efficiency. [9]

2-Skin sensorial wear comfort:

Skin sensorial comfort depends on the friction between fabric skin and surface roughness. Skin

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Receive Date: 03 August 2022, Revise Date: 03 September 2022, Accept Date: 11 September 2022

DOI: 10.21608/EJCHEM.2022.154211.6667

sensorial wear comfort is mainly determined by the fabric surface structure.

3- Ergonomic comfort:

While engaging in sports, significant movement of body parts happens. As a result, the sportswear must be flexible enough to allow the wearer to move freely. [10] [11]

4-The psychological aspect:

The psychological side of clothing is how the individual feels when wearing it, and it is impacted by aspects such as fashion, personal preferences, and ideology.

Textile finishing is the stage of textile production concerned with preparing products for end use, and it refers to a number of operations that have an impact on the quality of the fibre before and/or after fabric fabrication. [12-13]

Pre-treatment, coloration, and finishing are the three stages of finishing. There are various types of finishing to develop garment finishing and use emerging technologies one of which is nano-finishes. Nanomaterials and new manufacturing processes are driving textile finishing research. [12-14 -15]

Nanotechnology is described as the study, manipulation, and control of matter in order to improve its physical, chemical, and biological qualities. [16] Nanotechnology has advanced to the point that it is now possible to create, characterise, and tailor the beneficial features of nanoparticles for a wide range of applications.[17]

Many studies have been conducted on the use of nanoparticles to textile fabrics in order to develop finely finished textiles with a variety of valuable functional qualities, ranging from nanocomposites and nanofibers to smart polymeric coatings, which are being successfully used, another advantage that it allows for the production of multifunctional textile systems while preserving the natural features of the textiles, such as washability, softness, and elasticity. [18-16-19] Nowadays, nanotechnology is widely employed in a variety of equipment, coatings, floor coverings, and clothing. Given the harsh circumstances of numerous activities such as canoeing, skiing, and mountaineering, multipurpose clothing is constantly in demand. [20-21] Waterproof [20], water dirt repellence, antimicrobial characteristics [22], protection against UV radiation [23], self-cleaning, and flame retardancy are the most prevalent effects. [20-24-25]. Nanocellulose is a natural nanomaterial that is abundant in nature and may be derived from a variety of natural sources such as wood, cotton, and vegetable biomass. [26] Furthermore, due to its structure, Nanocellulose contains a large number of hydroxyl groups, which can be extracted from any cellulosic organic matter primarily through chemical hydrolysis, mechanical disruption, enzymatic, or a combination of two (or more) methods. [27] There are three varieties of nanocellulose: cellulose nanocrystalline, cellulose nano fibrillated, and bacterial nanocellulose. Although all varieties are chemically equivalent, they differ in shape, particle size, crystallinity, and other characteristics due to differences in sources and extraction processes. [28]

Nanocellulose has appealing properties such as high strength, excellent stiffness, large surface area, and low cost. Cellulose based fabrics are the most common material in wound care uses for its high absorption capacity. As a result, various research has focused on treating cotton to give bacterial resistance. [29-30] Nanocellulose has several applications in our daily lives, including biomedical devices, nanocomposite materials, textiles, and so on. [27] [26]

Nanocellulose and its uses are gaining popularity in both research and industry due to their appealing qualities such as good mechanical properties, large surface area, and natural properties that are 100% environmentally friendly. [27] [29] Nanocellulose has several applications in our daily lives, including biomedical devices, nanocomposite materials, textiles, and so on. [27].

This study was carried out to develop and add desirable functions to sportswear for polyester fabrics coated with nanocellulose.

2. Material and Experimental Techniques:

2.1 Material

2.1.1 Fabric samples

Polyester yarns were purchased from Misr-El-Mahala Company for Spinning and Textile- Egypt. The yarns had the following specification:

Table (1): specification of the yarns

twist	Twist Direction	z
	Twist Multiplier	4
	TPI	13.86
preparation		Raw
Type of fibers		Polyester 100%
Yarn number		1/12

The knitted fabric was produced at the knitted Factory in Salamon - El Mansoura. The fabrics had the following specification:

Table (2): structure of knitting fabric

Sample's size	40cm × 40cm
Knitting structure	Bird's eye or lacost 
Gauge	12
Machine	protti pv 91 flat knitting machine 

2.1.2 Nanocellulose:
The initial cellulose material was Egyptian cotton linter, which was obtained from Cotton Research Institute (CRI), Agricultural Research center, Giza, Egypt.

2.1.3 Chemicals
Sulfuric acid (H_2SO_4), Sodium bicarbonate ($NaHCO_3$), Hydrogen peroxide (H_2O_2), Sodium silicate ($Na_2SiO_3.9H_2O$), Sodium carbonate (Na_2CO_3), Magnesium sulphate ($MgSO_4$).

2.2 Method
2.2.1 Nanocellulose preparation methods
2.2.1.1 hydrolysis

The method of acidic hydrolysis was carried out according to (salah et al. 2015) with minor adaptations. The linter was ground in a Wiley mill and hydrolyzed without any chemical pre-treatment. The linter was mechanically stirred at a ratio of 1:20 (w/v) of aqueous concentrated sulfuric acid (20%, w/w) with a Teflon© bar dispersing element, at 45◦C, for 60 min. The produced nanosuspension was centrifuged for 15 min at 13,000 rpm in a high-speed refrigerated centrifuge CR22GIII, then the acid-treated sample was washed with 5% sodium bicarbonate until a pH (6–7) was reached, and the precipitate was resuspended in distilled water and dialyzed with tap water. The process from centrifugation through dialysis was repeated three time. [31]

2.2.1.2 Ultrasonic treatment process (Sonication):
The ultrasonic technology was used at Damietta University's college of applied arts. Elmasonic S 30 (H) 280w ultrasonic equipment with a frequency of 37 kHz. To absorb the heat generated by treatment operations, the treatment was performed in a plastic container placed in a bigger container filled with ice (ice bath). The treatments were carried out in 15-minute bursts of high-power ultrasonic irradiation, followed by another 15-minute break without ultrasonic irradiation, for a total of 300 minutes. During treatment, the temperature was measured and found to be in the 0 C range. Finally, the produced nano Nanocellulose was room temperature dried.[32]

2.2.2 Fabric treatment processes:
2.2.2.1 Treatment of polyester fabric:
The polyester fabric was immersed in 40g/l NaOH solution, it was dept in bath and boil for 1 h. then the fabric was taken out and immersed in water at boiling temperature for 10m and soaped.

2.2.2.2 Nanocellulose coated on Polyester fabric samples:
Polyester fabric samples were padded with varying concentrations of nano cellulose suspension (0.1g/l – 0.3g/l and 0.5g/l) of nano cellulose with 5gm/l surfactant. The mixture was then stirred at different RPMs for 30 min at 50 ◦C. Polyester fabric sample size (40x40) was immersed in padding liquor at room temperature for 10 min. and then passed through a two-bowel laboratory padding mangle. Which was running at a speed of rpm with pressure of 175kg/cm^2 using a 2dip- 2dip padding sequence at 70% expression for polyester fabric. The padded substrates were dried at 80°. the dried samples were cured preheated curing oven at 180° temperature for 3 min and microwaved for 60s. The treatment processes for the fabric samples were represented in the following Fig. (1)

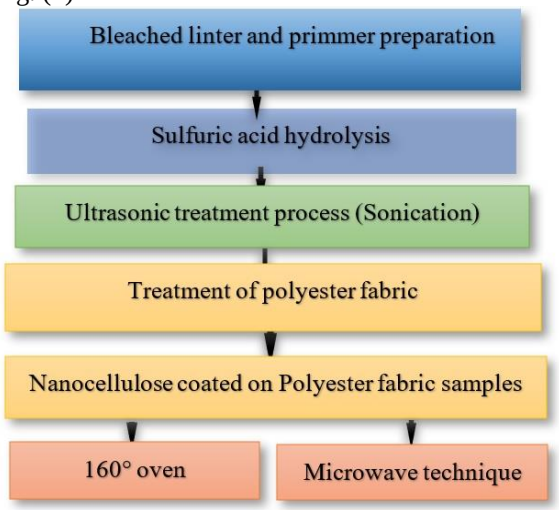


Fig. (1): Treatment processes for the fabric samples

2. 3 Evaluation tests
2.3.1.1 Particle size measurement
Nanocellulose particle size analysis was conducted by Dynamic Light Scattering (DLS) using a Zeta sizer NanoZS instrument, under the following conditions: dispersant water, material refractive index 1.47, dispersion refractive index 1.33, viscosity 0.8872 cP, temperature 24.9°C and general calculation model for irregular particles. The zeta-potential (estimated as surface charge) tests of the nanocellulose particles were conducted with the Zeta sizer NanoZS Instrument.

Table (3): sample detail and system conditions of Particle size

Material RI	**1.59**
Material absorption	**0.010**
Dispersant name	**water**
Dispersant RI	**1.330**
Viscosity(cP)	**0.8872**
Temperature(°C)	**24.9**
Count rate (kcps)	**192.8**
Cell description	**Clear disposable zeta cell**
Duration used (s)	**70**
Measurement position (mm)	**5.50**
attenuator	**6**

2.3.1.2 zeta potential measurement

The zeta-potential (estimated as surface charge) tests of the nanocellulose particles were conducted with the Zeta sizer NanoZS Instrument. Experiments were performed in a cuvette consisting of 4 ml 0.1 wt.% nano-cotton suspensions, solutions were all adjusted at pH values of 7. Nanocellulose zeta potential analysis was conducted by Dynamic Light Scattering (DLS) using a Zeta sizer NanoZS instrument, under the following conditions: dispersant water, Count rate (kcps) 263.5, Dispersant dielectric cons 78.5, viscosity 0.8872 cP, temperature 25.1°C, Dispersant RI 1.330, Measurement position (mm) 2.00, Cell description Clear disposable zeta cell and Material absorption 0.010

Table (4): sample detail and system conditions of zeta potential

Material RI	**1.59**
Material absorption	**0.010**
Dispersant name	**water**
Dispersant RI	**1.330**
Viscosity(cP)	**0.8872**
Temperature(°C)	**25.1**
Count rate (kcps)	**263.5**
Cell description	**Clear disposable zeta cell**
Zeta runs	**12**
Dispersant dielectric cons	**78.5**
Duration used (s)	**70**
Measurement position (mm)	**2.00**
attenuator	**5**

2.3.1.3 Transmission electron microscopy (TEM)

the morphology, shape, and size of nanocellulose were characterized using transmission electron microscope JOEL model 1200EX.

2.3.1.4 mechanical properties:

2.3.1.4.1 Burst resistance

ASTM D3787 is a test method specific to textiles that demonstrate significant ultimate elongations. using a ball burst test instrument, under the following conditions: batch reference (1912), temperature (19°C), relative humidity (64), load range (1000 N), extension range (100mm), speed (305mm/min), endpoint (95mm), preload (1.0N) and auto return was on. Three readings were taken for the polyester sample and then the mean was calculated.

2.3.4.1.2 Pilling resistance

Pilling resistance tests were evaluated according to the ASTM test method (3512). Tests were evaluated by using BS 5811 Pilling resistance of fabric (ICI method).

2.3.1.5 Fastness properties

2.3.1.5.1 Air permeability

Air permeability was determined by a Prolific air Permeability tester (FX3300 SDL) as per the standard procedure ASTM D737-04 (2008). five readings were taken for the polyester sample and then the mean was calculated.

2.3.1.5.2 UV protection properties (UPF)

UV protection factor was evaluated according to ASTM D6603, transmittance or blocking ultraviolet radiation through fabrics, and protection was rated as good, very good, excellent if their UPF values range from 15 to 25 to 39 or above 40.

2.3.1.6 Antibacterial test

Three microbial species were generously provided by the Agric. Microbiology Department, Fac. of Agriculture, Damietta University, Damietta, Egypt. Staphylococcus aureus, Pseudomonas aeruginosa, Bacillus cereus, and Escherichia coli were among the bacteria. The bacterial strains were kept at 5°C on NA medium slants until use. Before usage, the microbial strains were subcultured on fresh NA medium slants for 2 days at 37°C.

All bacterial strains were cultivated on NA slant for one day at 37 °C. Each slant received five millilitres of sterile saline solution (0.09% NaCl). Brushing the bacterial cells gently with a sterile inoculating loop loosened them. To remove all bacterial cells from the slants, a vortex mixer was employed for one minute. Antimicrobial activity was assessed using well diffusion techniques on Petri dishes containing approximately 20 ml of NA medium (El-Kadi et al., 2018). Using a sterile cotton swab, all plates were infected with the appropriate microbial strains. Subsequently. Fabric samples (1 cm X 1 cm) were cut and placed on the surface of the bacterial medium, where bacteria were dispersed. At 37°C, all plates were incubated. [33-34]

3. Results and discussions

3.1 Characterization of the prepared Nanocellulose

3.1.1 particle sizes and zeta potential

The statistical distribution of the nanoparticles is shown in Fig. 2. According to our observed results, it can be observed that most of the particles had dimensions in the nanoscale range. The average effective diameter of the particle sizes (~ 95%) was in the range of 255 and width of 39.9nm. Also, it was clear that the particles were not uniformly sized and varied both in length and width. This may be due to the processing conditions used for the preparation. It was clear that cellulose nanoparticles were successfully prepared since most of the particles had nanoscale dimensions.

Fig. (3) showed that the mean value of the zeta potential of the cellulose nanoparticles was found to be (-36.6 mv), zeta deviation was (4.56 mv) and conductivity was (0.00992ms/cm). the prepared nanocellulose is considered more stable. This result may be due to the absolute value of the prepared suspension of nanocellulose is higher than 25Mv. [35]

Also, the surface charge is the key factor for determining the stability of cellulose nanoparticles in colloidal suspension and the redistribution of nanoparticles from a coagulated state is caused by electric repulsion due to the presence of negative charges, Sumira R. and Himjyoti D, 2020.[36] On the other hand, the stability of the prepared cellulose nanoparticles may be due to the repulsive forces between the charges on the surface of the nanoparticles and charges due to the particles present in the solution were strong enough, hence they do not come together and don't stick to form an aggregate. Simultaneously, other particles join the growing aggregate.

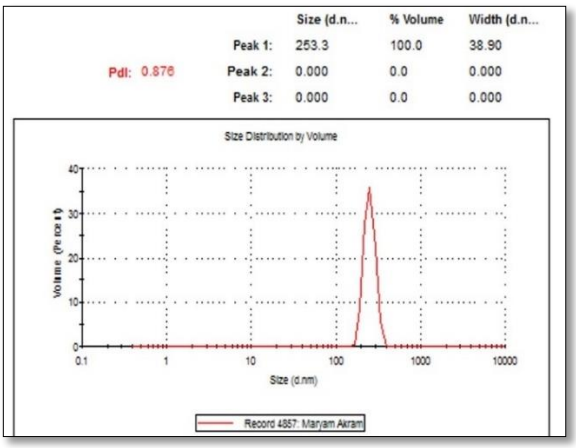


Fig. (2) Particle size distribution of the samples

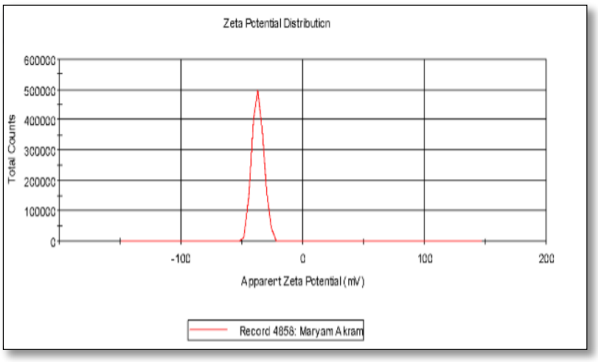


Fig. (3) Zeta-protentional of the sample in 300 min.

3.1.2 TEM of the prepared nanocellulose

TEM was shown in Figure 4. It can be observed that (TEM) image shows that the prepared nanocellulose has a rod-like structure with a different diameter of about (19.23, 16.66, 11.13, 8.88, and 8.25) nm. cellulose nanorods are agglomerated in a few areas, whereas they look quite separated in many other places. The distribution range of the particles was quite high and it is clear from the images that the dimensions of the particles were in the nanoscale range (less than 500 nm). These results were in accordance with the results obtained by Divya et al. (2022) [37] and also with the explanation of Tiffany & Dawn which pointed out that the TEM image of the prepared nanocellulose by sulfuric acid hydrolysis of cotton filter paper, with an average particle size of 115 nm in length and 7 nm in width. These results are close to the research described by Li Fan, Hui Zhang, et al. [38] indicated that the CNC has a rod-like structure with a diameter of about 10 nm.

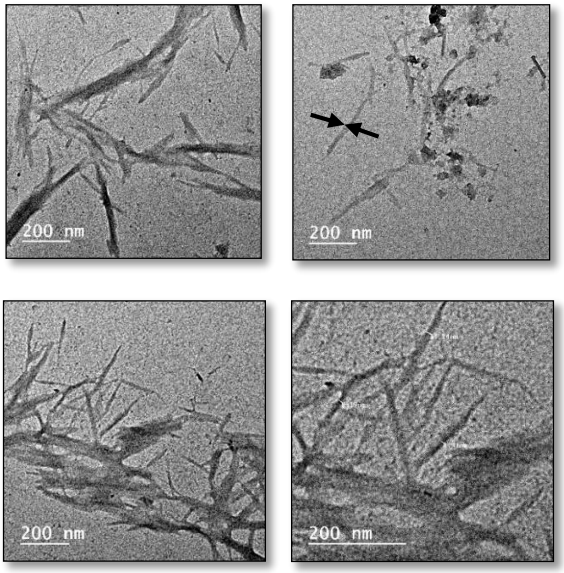


Fig. (4) TEM of the prepared nanocellulose

3.1.3 nanocellulose and polyester fabric:

To explain and prove a stable link between the nanocellulose and polyester fabric. Chattopadhyay DP and Patel BH pointed out that the dispersion of cellulose nanoparticles on the surface of the polyester and their penetration in the polymer matrix were examined by image analyser (100 X). [39] The prepared cross sectional and longitudinal sections were further stained with direct dye and examined under image analyser. Cellulose particles applied on 100% polyester fabric; the treated fabric was then stained with a direct dye (Congo Red BDC) to highlight the cellulose particles. Deposition of cellulose particles is seen on the surface of polyester fiber, from the longitudinal view of the polyester. Dispersion of these particles in the polymer matrix is also observed which represents the cross-sectional view of polyester fabric. The SEM images of polyester fiber surfaces after the nano-cellulose treatment. The Micro photographs captured at different magnifications i.e. 500 X, 1000 X, 1500 X and 2000 X show that the fiber surface is covered with nano-cellulose particles after treatment. The FTIR spectra of the polyester fabric before and after nano cellulose treatment are illustrated and the peaks

in the IR spectra of the polyester loaded with nano cellulose and untreated fabric appeared in the range of 600- 4000 cm-1. The waves were assigned as follows: 1715 cm-1 (C=O), 1409 cm-1 (aromatic ring), 1331 cm-1and 1021 cm-1 (carboxylic ester or anhydride), and 1021 cm-1 (O=C–O–C or secondary alcohol), 967 cm-1 (C=C), 869 cm-1 (five substituted H in benzene). The peak at 1409 cm-1 corresponded to the aromatic ring. It was the characteristic absorption peak of PET. The peak at 1715 cm-1 was assigned to the ester group. the spectra also confirmed the presence of cellulose from the absorption peaks in the region of 3600-3100 cm^{-1} due to the stretching of –OH group; at 3000 to 2800 cm^{-1} to the CH stretching; 1642 cm^{-1} across from the H-O-H bending of the absorbed water; symmetric C-H bending occurred at 1430 cm-1; at absorption band 898 cm-1, assigned to C–O–C stretching. [40]

3.2 Characterization of the treated polyester fabric samples

3.2.1 Mechanical properties of the treated fabrics

3.2.1.1 Burst resistance of the treated fabrics

Three readings were taken for the polyester sample and then the mean was calculated. The results presented in Table (5) showed that in the oven curing technique, the burst strength of polyester knitted fabric increased as the nanocellulose concentration increased till reached 0.5. on the other way, in the microwave curing technique, the bursting strength has its maximum value with nanocellulose concentration (0.1). Bursting strength decreased with an increase in nanocellulose concentration. This result in accordance with the results obtained by Ali Hebeish et al. (2012) [39], who pointed out that with microwave curing, the tensile strength decreases from the percentage of 45-49% after finishing in the absence and presence of β-CD, respectively. The explanation of the mentioned results may be due to that microwave curing technology can generate heat uniformity throughout the cotton fabric. Microwave radiation is absorbed by molecules that have resonant frequencies in the microwave spectral region. When an electric field is applied at microwave frequencies, polar molecules rotate to align their dipole moment with the changing electrical friction between the rotating molecules. Thus, when the wet cotton fabric is exposed to dielectric energy, the water molecules preferentially absorb power and are vaporized. Cotton textiles absorb very little power in the microwave range, but are heated by heat transfer and the heat increased inside the sample first, then transferred to its outer part. In contrast, the conventional curing system involves heat transfer to the cotton textiles by convention, conduction, and radiation. The surface of the textile becomes hotter than the interior which leads to baking and non-uniform distribution of crosslinks

Table (5): burst resistance of polyester and polyester treated fabrics

samples	1	2	3	mean
polyester	1044	946	914	968
0.1 nanocellulose 160° oven	1076	1218	1225	1173
0.3 nanocellulose 160° oven	1158	1193	1212	1187
0.5nanocellulose 160° oven	1203	1210	1343	1252
0.1 nanocellulose microwave	920	950	891	920
0.3 nanocellulose microwave	876	796	919	864
0.5 nanocellulose microwave	942	876	779	865

3.2.1.2 Pilling resistance of the treated fabrics

The results presented in Table (6) showed that the pilling resistance of polyester knitted fabric increased with nanocellulose concentration increased for both conventional and microwave curing. The reason may be due to the resistance of knitted fabrics to pilling depending on the density of the fabric, when the length of the knitted fabric loop decreases and the surface density increases, the resistance to pilling grows.

Table (6): Pilling resistance of polyester and polyester treatment fabrics

samples	result
polyester	2/5
0.1Nanocellulose 160° oven	3/5
0.3nanocellulose 160° oven	3/5
0.5nanocellulose 160° oven	4/5
0.1 nanocellulose microwave	4/5
0.3nanocellulose microwave	4/5
0.5nanocellulose microwave	4/5

3.2.2 Fastness of the treated fabrics

3.2.2.1 Air permeability of the treated fabrics

The results presented in Table (7) showed that the Untreated sample showed the highest value of air permeability. As the concentrations of nanocellulose increased, the air permeability of polyester knitted fabric decreased and was still lower than that of the control sample. It may be due to the resistance of the nanocellulose present in the polymer matrix toward the flow of air through the fabric sample. [40]. Another assumption is that the air permeability of nanocellulose added to polyester fiber is lower compared to the normal fiber because of the

resistance developed in the polymer matrix against the stream air [41]. The air permeability of the coated samples with microwave curing is better than that of conventional curing and the optimum concentration of the coated nanocellulose was 0.1.

Table (7): Air permeability of polyester and polyester treatment fabrics

samples	1	2	3	4	5	Mean ($cm^3/cm^2/s$)
polyester	187	185	179	176	177	180.8
0.1nanocellulose 160° oven	178	176	170	161	167	170.4
0.3nanocellulose 160° oven	168	170	167	162	159	165.2
0.5nanocellulose 160° oven	139	148	132	145	130	138.8
0.1nanocellulose microwave	197	194	193	184	188	191.2
0.3nanocellulose microwave	177	161	160	176	169	168.6
0.5nanocellulose microwave	166	176	162	164	158	168

3.2.2.2 UPF values of polyester treatment fabrics

UPF is the scientific term used to indicate the amount of UV protection provided to the skin by fabric. UPF is defined as the ratio of the average effective irradiance calculated for skin to the average UV irradiance calculated for skin protected by the test fabric, Salah M, (2012) [42]. The UPF is a number that indicates how many times the solar UV radiation reaching the epidermis is reduced by the presence of the fabric. In particular, solar radiation is converted into UV radiation biologically effective for erythema. Ultraviolet radiations (UVRs) can be divided into several classes, that is Ultraviolet A (UVA [400-315 nm]), and Ultraviolet B (UVB [315-280 nm]). UVBs cause severe damage to the skin, such as sunburns and cataracts, since they have higher energy as compared to UVA, Polefka et al. 2012, [43]. Simultaneously, UVA can cause skin aging and wrinkling. It has been noted that the fabric structure is the most critical factor in the UV protection performance of a fabric. Closer and tighter structures exhibit fewer open spaces between the yarns that form the fabric, thus allowing less UV radiation to be transmitted through the fabric, Aguilera et al. 2014, [44]. The results were obtained by Louris et al. 2019 [44], who pointed out that the knitted structure of the polyester fabric is Lacoste which represented the lowest UPF among the other knitted fabric structures. The results presented in Table (8) and Fig. 5 showed enhancement of UPF in the presence of nanocellulose coated the polyester knitted fabric, and UPF increased after increased concentration of nanocellulose, especially when used microwave curing

Table (8). UPF values of polyester and polyester treatment fabrics

samples	UPF	UVB	UVA
polyester	8.49	11.15	8.3
0.1Nanocellulose 160° oven	9.80	9.70	9.6
0.3nanocellulose 160° oven	13.3	6.31	13.07
0.5nanocellulose 160° oven	13.8	6	13.57
0.1nanocellulose microwave	10.4	8.11	10.23
0.3nanocellulose microwave	16.2	5.21	6.572
0.5nanocellulose microwave	18.4	4.46	5.78

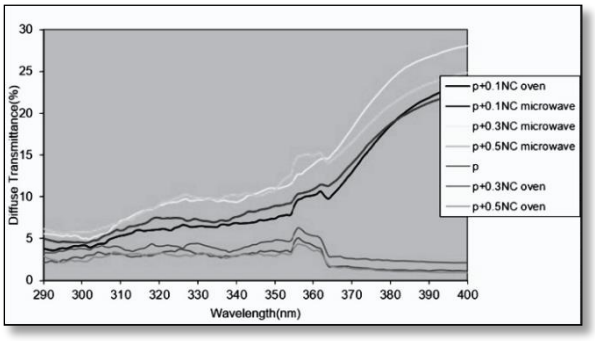


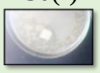
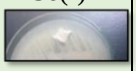
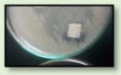
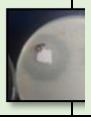
Fig. (5) UPF of polyester and polyester treatment fabrics

3.2.3 Antibacterial test

Antimicrobial properties for polyester fabric which coated with nanocellulose are shown in Table (9). The results showed that samples coated with (0.5 gm/l) of nanocellulose and cured using the microwave for (30 sec) have excellent antimicrobial activity and scored best result antibacterial activity against (E. coli - S. aureus - Pseudomonas aeruginosa - Bacillus cereus), followed by the sample coated with (0.3g/l) of nanocellulose and cured by using the microwave for (30 sec), and finally the sample coated with (0.3g/l) of nanocellulose (0.1g/l). Overall the samples cured by using microwave achieved the best results compared to the samples cured by conventional technique. This result was confirmed by the data mentioned by Mohd F and Norizan N, 2010 [45]. This research has revealed that modification of nanocellulose is undoubtedly beneficial in combating viruses and bacteria. A study showed that the

functionalization of nanocellulose with a variety of functional groups is a key factor for success in enhancing the antimicrobial properties against numerous microbes.

Table (9). Antibacterial test of polyester and polyester treatment fabrics

Samples	*E. coli*	*Staphylococcus aureus*	*Pseudomonas aeruginosa*	*Bacillus cereus*
polyester	0 	0 	0 	0 
0.1 NC 160° oven	0 	17(I) 	15(I) 	0 
0.1 NC microwave	21 	30(I) 	36(I) 	0 
0.3 NC 160° oven	0 	10(I) 	0 	0 
0.3 NC microwave	40 	29(I) 	20 	19 
0.5 NC 160° oven	19 	25 	25I 	0 
0.5 NC microwave	37 	28(I) 	23 	21 

4. Conclusions:

In the current study, we prepared nanocellulose from cotton wastes using acid hydrolysis followed by mechanical pulverization and 37 kHz high power ultrasonic for 300 min. The prepared nanocellulose with varying concentrations (0.1g/l – 0.3g/l and 0.5g/l) with 5g /l surfactant, was used as a coating for Polyester fabric samples. The data obtained showed that the polyester fabrics have excellent antibacterial activity, with good UPF, burst resistance, air permeability, and fastness properties among the control.

- In the oven curing technique, the burst strength of polyester knitted fabric increased as the nanocellulose concentration increased till it reached 0.5. on the other way, in the microwave curing technique, the bursting strength has its maximum value with nanocellulose concentration (0.1). Bursting strength decreased with an increase in nanocellulose concentration. Because of the non-uniform distribution of crosslinks in the fabric while cured by microwave.
- Pilling resistance of polyester-treated fabric increased with nanocellulose concentration for both conventional and microwave curing.
- In the microwave curing technique, the air permeability of the coated samples was better than in the oven curing technique, and the optimum concentration of the coated nanocellulose was 0.1.
- UPF increased after coating fabric and with an increased concentration of nanocellulose, especially when used microwave curing.
- In the microwave curing technique, the antimicrobial activity has its maximum value with nanocellulose concentration (0.5 gm/l).

These results reveal that the application of nanocellulose of polyester fabric might be a promising more ductile, lightweight and cost-effective substitute for conventional sportswear applications.

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