Dynamic thermo-physiological comfort of a recycled Denim nano-layered fabric

DOI: 10.35530/IT.076.04.2024163

SOFIEN BENLTOUFA HIND ALGAMDY

ABSTRACT – REZUMAT

Dynamic thermo-physiological comfort of a recycled Denim nano-layered fabric

This study investigated the dynamic thermo-physiological comfort of a recycled Denim nano-layered fabric. The top layer of the Multilayered Denim fabric was recycled Denim. The semi-permeable nanomembrane was chosen due to its high-water vapour permeability and waterproof properties. A nonwoven fabric was added to the garment as an extra layer to provide shape and support and avoid direct contact with the skin. A double-faced adhesive grid was used to ensure bonding between the various layers.

The breathability of used fabrics was studied based on the air permeability, water vapour resistance, and relative permeability using the Permetest according to the ISO 11092 standard. To study the dynamic of the thermo-physiological comfort, the dynamic cooling heat flow during evaporation was visualised. Results showed adding a semi-permeable nanolayer decreased the air permeability by about 16% compared to a simple Denim fabric. Conversely, the water vapour permeability was enhanced to 48% when the nanolayer foil was added. It was found that a multilayered Denim fabric had a better cooling feeling at the skin's first contact stage and equilibrium compared to a simple fabric.

Keywords: *recycled denim, nanolayer, breathable, dynamic heat flow*

Confortul termofiziologic dinamic al unui material textil nano-stratificat din denim reciclat

Acest studiu a investigat confortul termofiziologic dinamic al unui material textil nano-stratificat din denim reciclat. Stratul superior al materialului textil denim multistrat a fost denimul reciclat. Nanomembrana semipermeabilă a fost aleasă datorită permeabilității ridicate la vapori de apă și proprietăților sale de impermeabilitate. Un material nețesut a fost adăugat la produsul de îmbrăcăminte ca un strat suplimentar pentru a oferi formă și suport și pentru a evita contactul direct cu pielea. A fost utilizată o grilă adezivă cu două fețe pentru a asigura aderența între diferitele straturi.

Respirabilitatea materialelor textile utilizate a fost studiată pe baza permeabilității la aer, a rezistenței la vapori de apă și a permeabilității relative utilizând Permetest, în conformitate cu standardul ISO 11092. Pentru a studia dinamica confortului termofiziologic, a fost vizualizat fluxul de căldură dinamic pentru răcire în timpul evaporării. Rezultatele au arătat că adăugarea unui nanostrat semipermeabil a redus permeabilitatea la aer cu aproximativ 16% în comparație cu o țesătură denim simplă. În schimb, permeabilitatea la vaporii de apă a crescut cu 48% la adăugarea foliei nanostratificate. S-a constatat că o materialul textil denim multistrat creează o senzație de răcire în prima etapă de contact și echilibru cu pielea, comparativ cu un material textil simplu.

Cuvinte-cheie*: denim reciclat, nanostrat, respirabil, flux termic dinamic*

INTRODUCTION

The Denim market has been a cornerstone of the fashion industry for decades, characterised by its enduring popularity and versatility [1–4]. Denim jeans, jackets, and other apparel have become a staple in wardrobes worldwide, driven by comfort, durability, and style [5, 6].

A growing emphasis on sustainability has led to increased demand for eco-friendly Denim products [7, 8]. Brands are responding by adopting sustainable practices, such as using organic cotton, reducing water consumption, and implementing ethical sourcing.

The rise of personalisation has fuelled a trend towards customised Denim. The fast-fashion industry has played a significant role in popularising Denim, offering affordable and trendy options to the mass market [9, 10].

Multilayered textile fabrics are those composed of multiple layers of fabric or non-fabric materials, often bonded or laminated together to achieve specific properties or functions [11, 12]. These layers can be made from various materials, including natural fibres (like cotton, wool, and silk), synthetic fibres (like polyester, nylon, and acrylic), or blends of these [13–15]. Multilayered fabrics were used to enhance fabric performance, like durability, insulation, waterproofing, windproofing and UV protection.

Common types of multilayered fabrics are laminated, bonded fabrics and composite fabrics. Multilayers can create unique textures, patterns, and visual effects. They can serve as carriers for coatings, laminates, or other treatments [16].

Breathability in textiles refers to their ability to allow air and moisture to pass through them [17]. It's a crucial factor in various applications, especially clothing

and bedding, as it directly impacts comfort and overall well-being [18].
The breathability of a textile is a vital consideration for various applications. By understanding the factors that influence breathability, you can select fabrics that are best suited for your specific needs [18]. Breathable fabrics help to regulate body temperature by allowing moisture to evaporate, preventing discomfort and skin irritation [17]. Poorly breathable fabrics can trap moisture, creating a breeding ground for bacteria and fungi, which can lead to skin infections and other health problems. In athletic wear, breathable fabrics help to wick away sweat, improving performance and comfort. Breathable fabrics can help to prevent moisture buildup, which can contribute to fabric degradation and reduce the lifespan of the garment.
Waterproof breathable fabrics differ from conventional coated materials owing to distinct characteristics of waterproofness and breathability. These fabrics function similarly to human skin. Numerous breathable and waterproof fabrics have been developed to minimise wearer heat stress through efficient moisture vapour transfer while preventing external water penetration. Several factors influence the breathability of a textile, like fibre type, fabric structure and finishing process [19–21]. Natural fibres like cotton, linen, and wool generally have better breathability due to their porous structure. Synthetic fibres like polyester and nylon can vary widely in breathability [22]. Some, like microfibre, can be highly breathable. Plain weave fabrics tend to be more breathable than twill or satin weaves [18, 23]. Jersey knit fabrics are generally more breathable than rib knit or French terry. Heavier fabrics may be less breathable than lighter ones, as they have a denser structure [23]. Treatments like water repellents or finishes can affect breathability [24, 25]. Some treatments can reduce the fabric's ability to absorb moisture, which can also impact its breathability.
Thermal Evaporative Resistance (RET) is used to quantify breathability and water vapour transport via textiles [26, 27]. Water vapour resistance refers to a fabric's capacity to transfer moisture vapour through it [28]. The less resistance there is, the more breathable the cloth is. The ISO 11092 standard defines the test technique.
As a result, it is fundamental to study the kinetics of water vapour transport. Based on the review of the literature investigation described in this section, there is an absence of studies dealing with the thermo-physiological comfort using layered Denim materials.
In this study, a layered denim fabric was developed. The top layer was made of recycled denim fabric. The semi-permeable material was incorporated due to its exceptional water vapour permeability and waterproof properties. A nonwoven fabric is utilised as an additional layer within a garment to provide shape and support while avoiding direct contact with the nanolayer semi-permeable membrane. All layers were bonded using a double-face adhesive grid. The Breathability of designed fabrics was evaluated regarding air permeability, water vapour resistance, and relative permeability. The dynamic of the evaporative cooling heat flow was studied using Permetest, based on the ISO 11092 standard.

MATERIALS AND METHODS

Denim nanolayered fabric design

Figure 1 illustrates the different fabric components of each layer, with denim fabric considered the top layer. A semi-permeable membrane was used due to its reparability, high water vapour permeability and waterproofing.
Table 1 presents the different properties of the different layers used in this study.
A nonwoven interfacing fabric was selected as an extra layer in a garment to provide shape and support and avoid direct contact with the skin of the nanolayer semipermeable foil. A double-face adhesive grid was placed between two adjacent layers to ensure adherence.
Figure 2 illustrates the different sample layout designs. Fabric (A) is a Denim fabric considered as a reference sample. The (AC) layout was made with Denim fabric (A) as a top layer and a nonwoven interfacing. In the case of the (AB), the nonwoven interfacing was replaced by the Semi-permeable foil PU Nanolayer (B). The sample (ABC), three different

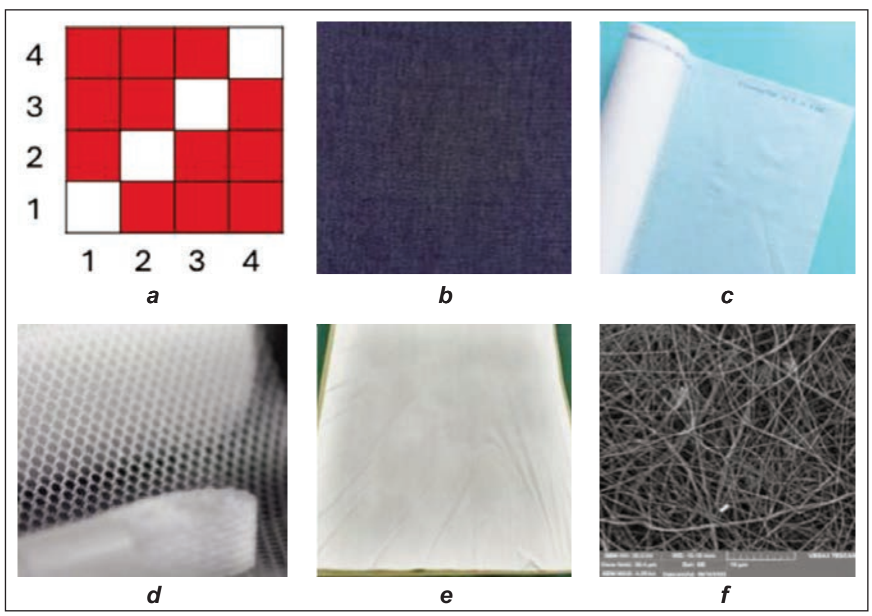

Fig. 1. Fabric Layers component: *a* – Denim fabric designs; *b* – Denim fabric; *c* – nonwoven interfacing; *d* – PA66 adhesive Monocomponent Cobweb; *e* – Semi-permeable foil PU Nanolayer; *f* – SEM image of PU Nanolayer foil

Table 1

LAYERS COMPOSITION PROPERTIES					
Layer	**Designation**	**Material**	**Mass per unit area (g/m^2)**	**Fibre diameter (μm)**	**Thickness (mm)**
A	Recycled Denim fabric	100% recycled cotton	180±4	18.3±1.7	0.62±0.02
B	Semi permeable foil	PU	3.1	0.180	0.02±0.01
C	Nonwoven interfacing	85% PA66/15% recycled PET	35	-	0.12
	Double-face adhesive grid	PA66	6	-	0.01±0.005

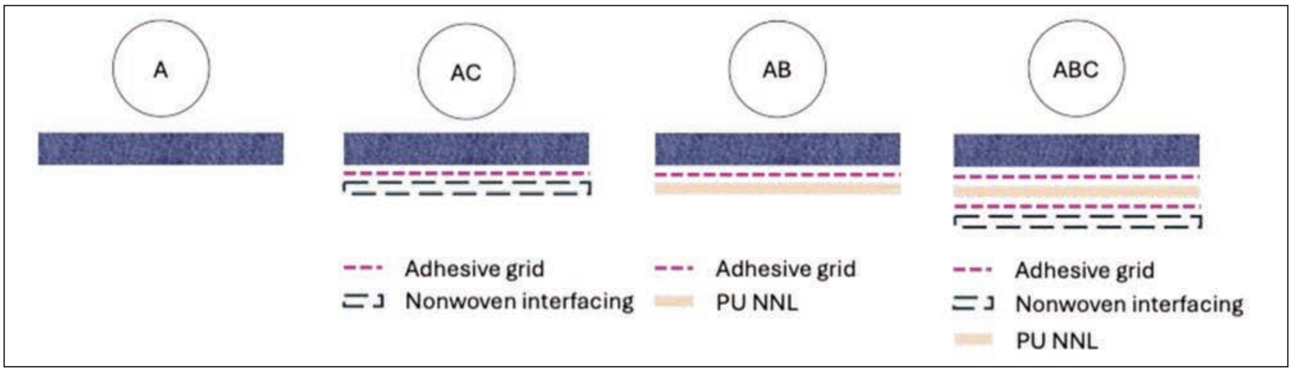

Fig. 2. Different layout layers of used samples

layers were composed of Denim (A), Semi-permeable foil PU Nanolayer (B) and nonwoven interfacing (C). The bonding process of all layers was carried out using a heat press machine at 115ºC, and the heat-pressing time was set to 30 seconds.

Air permeability

Air permeability measurements are made using the SDL Atlas Air permeability instrument according to EN ISO 9237 standard with 100 Pa air pressure.
Table 2 states the properties of the different layer configuration samples.

Table 2

DIFFERENT LAYERS CONFIGURATIONS PROPERTIES			
Sample	**Mass per unit area (g/m^2)**	**Thickness (mm)**	**Air permeability (mm/s)**
A	180±4	0.62±0.02	465±10
AC	220±3	0.65±0.03	416±7
AB	189±1	0.62±0.04	402±3
ABC	228±5	0.66±0.04	389±5

Based on table 2, the thickness of the layered fabric is not the direct sum of each fabric's thickness. This is due to the bonding process where pressure was applied.

Thermo-physiological comfort

The relative water vapour permeability (%) and resistance (m^2Pa/W) values of different samples were tested using the Permetest instrument. In this instrument, the measuring head of the small Skin Model is covered by a resistant semi-permeable foil, which prevents the liquid water transport from the measuring system into the sample. A computer-evaluated sensing system quickly records cooling heat flow caused by water evaporation from the thin-porous layer. Regarding heat transfer, the Permetestent presents the model of real human skin. The instrument provides all kinds of measurements, like the ISO Standard 11092. The results are evaluated by the identical procedure as required in this standard and are treated statistically, displayed and recorded for future use [29].

Measurements conditions

After conditioning the fabrics for 24 hours under the standard atmospheric conditions of 20 ± 2 °C temperature and 65 ± 2 % relative humidity, all measurements were conducted.

RESULTS AND DISCUSSION

In this section, the effect of adding layers to a recycled Denim fabric on the thermo-physiological comfort was investigated. Then, the cooling heat flow during the evaporation of different layer configurations was studied.
Table 3 illustrates the water vapour relative permeability and resistance of the different designed fabrics.
Table 3 indicates that sample ABC is more competitive than the other samples. The relative water vapour permeability was increased to 47.63% when comparing Denim Fabric (A) to the layered sample (ABC). And the water vapour resistance was dropped to 34.37%.

Table 3

WATER VAPOUR RELATIVE PERMEABILITY AND RESISTANCE OF DESIGNED LAYERED FABRICS				
Water vapour	**Samples**			
	A (reference)	**AC**	**AB**	**ABC**
RWVP (%)	52.7±2.3	39.8±2.1	59.5±2.6	77.8±3.1
RET (m^2Pa/W)	6.4±0.3	7.1±0.4	5.6±0.2	4.2±0.1

Concerning the air permeability (table 2), it was decreased to 16.34% in the case of the sample (ABC) compared to sample (A), the Denim fabric. This is caused by the densities of dry air and water vapour. Humid air is less dense than dry air, and subsequently, we have more mobility in terms of water vapour particles compared to dry air particles. Also, during the drying process, the evaporation front drops from the outer surface to internal pores, as capillary transport of the liquid takes place in the inter-fibre spaces, governed by the concentration gradient of water between wet and dry surfaces. The evaporation of water in those holding regions involves the movement of condensed water before it is evaporated, which increases its evaporation duration [30]. The evaporation duration is reduced by increasing the contact surface between the liquid in the textile structure and the air in the external environment, which promotes water vapour evaporation.

The evaporative cooling heat flow kinetics under 1 m/s of air velocity are presented in figure 3.

Based on figure 3, the double adhesive grid and the nonwoven interfacing fabric have no significant effect on the water vapour diffusion. There were no noticeable changes between A and AC and between AB and ABC concerning the evaporative cooling heat flow.

Figure 3 suggests that displaying the cooling heat flow dynamics resulted in three phases. In the beginning, the maximum cooling heat flow was measured as the difference between the sample temperatures at 20±2°C and 65±2% relative humidity and the temperature at the top of the measuring heat, which was approximately 18±2°C due to evaporation from the semi-permeable foil. Throughout the second stage, also referred to as the transition phase, the cooling heat flow drops to a minimum before rising to an equilibrium value, marking the initiation of the third stage, the steady state phase.

At 0 seconds, the sample (ABC) had an evaporative cooling heat of 153.3±5.4 W, whereas the basic Denim sample (A) had 87.4±7.8 W. During evaporation on the Permetest device, samples initially maintained at room temperature (20±2°C) had warmer temperatures than those in the ventilation channel (18±2°C) resulting from evaporation from the semi-permeable membrane covering the top of the measuring heat. As a result, the last-mentioned was not heated since the fabric was hotter than the semi-permeable membrane top side that was placed on top of it.

In the second stage, to regulate the temperature between the fabric and the measuring top head, the heat flow fell to 39±1.3 W in the sample (ABC) versus 33.1±2.1 W in the basic Denim sample (A). In the final phase, the reducing heat flow increased until equilibrium was established. The increased flow is caused by evaporation from the semi-permeable membrane, which cools the fabric's top surface. The equilibrium cooling heat flow is defined as the continuous penetration of water vapour through a textile fabric. Figure 4 additionally demonstrates that the fabric (ABC) feels cooler than the simple Denim. In fact, at equilibrium, the evaporative cooling heat flow was 52.7±3.2 W in the case of the simple Denim Fabric compared to 61.7±2.4 W in the case of the sample (ABC). As a result, adding the PU membrane to a layered fabric leads to an enhancement of about 17% in cooling feeling. This is due to the inclusion of a semi-permeable PU membrane in the fabric, which improves water vapour permeability due to the higher number of pores distributed compared to the Denim fabric. The reference sample, made of 100% is significantly less cool than fabrics that have a semi-permeable PU barrier. Cotton fibre, as a natural cellulosic fibre, has excellent absorbency due to its multitude of hydrophilic –OH groups. The hydroxyl groups are univalent OH groups and polar. Consequently, they attract polar water molecules. As a result, the OH groups are responsible for the fibre's ability to absorb moisture [31, 32].

So, when textile fabrics formed of hydrophilic fibres absorb humidity, the fibres swell, resulting in a decrease in the fabric's porosity [33], and the phenomenon of water vapour condensation occurs.

Samples which include PU semi-permeable membranes are waterproof and hydrophobic foils that repel water vapour molecules and resist water vapour absorption.

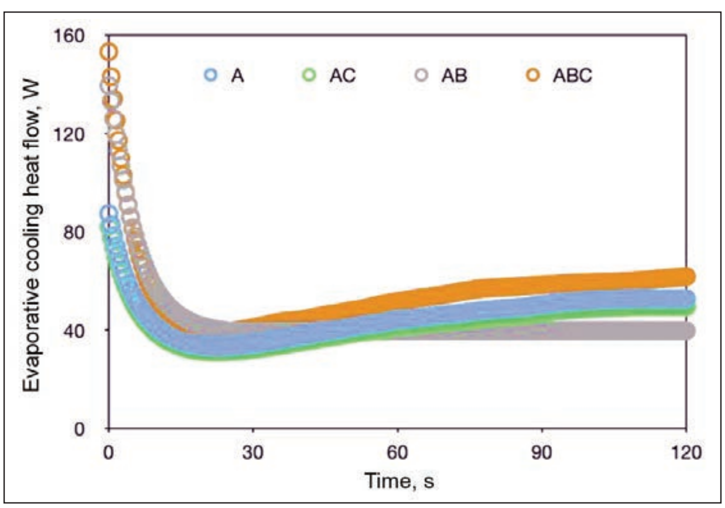

Fig. 3. Evaporative cooling heat flow kinetics of used samples

CONCLUSION

The dynamic thermo-physiological comfort of a recycled denim nano-layered fabric is highlighted in this study. A nonwoven fabric was added to the garment as an additional layer to give it shape, support and prevent nonmembrane direct skin contact. The top layer of the multilayered fabric was made of 100% cotton recycled denim, and a PU semi-permeable nanomembrane as a middle layer was selected because of its high-water vapour permeability and waterproof qualities. The different layers were bonded together using a double-faced adhesive grid.

Relative water vapour permeability (RWVP) and water vapour resistance (RET) were measured using the Permetest. The evaporative cooling heat flow was visualised using the same apparatus.

The use of a PU waterproof semi-permeable nanomembrane was noticed to significantly improve breathability. Comparing the simple Denim fabric to the layered sample with the PU membrane, the air permeability was decreased to 16.34%, the relative water vapour permeability was increased to 47.63% and the water vapour resistance was dropped to 34.37%.

When examining the dynamics of evaporative cooling heat flow, three stages were noticed. The difference between the sample temperatures at 20±2°C and 65±2% relative humidity and the temperature at the top of the measuring heat, which was within 18±2°C, caused by evaporative cooling from the semi-permeable membrane, was the initial phase of the maximum cooling heat flow. The cooling heat flow decreases to a minimal value during the second stage, referred to as the transition phase, and then rises to an equilibrium value, signifying a steady state phase. Based on the evaporative cooling heat flow kinetics, it was found that adding the PU nanomembrane to a layered fabric leads to an enhancement of about 17% in cooling feeling compared to a simple Denim fabric.

Future frameworks will be constructed on how external factors, such as temperature and relative humidity, affect the dynamics of the cooling heat flow of nano-layered Denim fabric.

ACKNOWLEDGMENTS

The author would like to acknowledge the Deanship of Graduate Studies and Scientific Research, Taif University for funding this work.

REFERENCES

[1] Harpa, R., Piroi, C., Cristian, I., *Ripped Jeans: The Discrepancy between Quality Assurance Strategies in the Sustainable Production of Denim and the Market Strategies of Fashion Manufacturers*, In: The 18th Romanian Textiles and Leather Conference, 2023, https://doi.org/10.2478/9788367405133-023

[2] Kılıç, G.B., *Strength and Elasticity Properties of Denim Fabrics Produced from Core Spun Yarns*, In: Tekstil ve Konfeksiyon, 2024, 34, 1, https://doi.org/10.32710/tekstilvekonfeksiyon.1121292

[3] Haque, MdE., Rahman, MdB., Kafi, W., Kaiser, MdSU., Dey, A., *Minimization of Air Consumption and Potential Savings of Textile Denim Fabric Manufacturing Process*, In: Journal of Textile Science and Technology, 2023, 09, 01, https://doi.org/10.4236/jtst.2023.91005

[4] Nahar, N., Haque, MS., Haque, SE., *Groundwater conservation, and recycling and reuse of textile wastewater in a denim industry of Bangladesh*, In: Water Resources and Industry, 2024, 31, https://doi.org/10.1016/j.wri.2024.100249

[5] Toyonori, N., Kazuya, T., Hiroyuki, K., Toshio, M., *Influence of straight jeans' rise size on clothing comfort*, In: Journal of Textile Engineering, 2016, 62, 1, https://doi.org/10.4188/jte.62.7

[6] Çoruh, M., Vural, T., Çoruh, E., *A scale development study to evaluate the physical comfort of denim jeans*, In: Tekstil ve Konfeksiyon, 2011, 21, 1

[7] Periyasamy, AP., Periyasami, S., *Critical Review on Sustainability in Denim: A Step toward Sustainable Production and Consumption of Denim*, In: ACS Omega, 2023, 8, 5, https://doi.org/10.1021/acsomega.2c06374

[8] Sneha, B., *Advances Towards Sustainable and Eco-Denim Fashion*, In: International Journal For Multidisciplinary Research, 2023, 5, 5, https://doi.org/10.36948/ijfmr.2023.v05i05.7599

[9] Miyauchi, R., Zhou, X., Inoue, Y., *Design Elements That Increase the Willingness to Pay for Denim Fabric Products*, In: Textiles, 2023, 3, 1, https://doi.org/10.3390/textiles3010002

[10] Ma, Y., Zeng, B., Wang, X., Byrne, N., *Circular Textiles: Closed Loop Fiber to Fiber Wet Spun Process for Recycling Cotton from Denim,* In: *ACS Sustainable Chemistry and Engineering*, 2019, 7, 14, https://doi.org/10.1021/acssuschemeng.8b06166

[11] Shabaridharan, K., Das, A., *Analysis of thermal properties of multilayered fabrics by full factorial and Taguchi method*, In: Journal of the Textile Institute, 2014, 105, 1, https://doi.org/10.1080/00405000.2013.809186

[12] Ji, Y., Sun, Y., Muhammad, J., Li, X., Liu, Z., Tu, P., et al., *Fabrication of Hydrophobic Multilayered Fabric for Passive Daytime Radiative Cooling*, In: Macromolecular Materials and Engineering, 2022, 307, 4, https://doi.org/10.1002/mame.202100795

[13] Ziaei, M., Ghane, M., *Thermal insulation property of spacer fabrics integrated by ceramic powder impregnated fabrics*, In: Journal of Industrial Textiles, 2013, 43, 1, https://doi.org/10.1177/1528083712446384

[14] Stojanović, G.M., Radetić, M.M., Šaponjić, Z.V., Radoičić, M.B., Radovanović, M.R., Popović, Ž.V., et al., *A textile-based microfluidic platform for the detection of cytostatic drug concentration in sweat samples*, In: Applied Sciences (Switzerland), 2020, 10, 12, https://doi.org/10.3390/app10124392

[15] Sukumar, N., Gananvel, P., Dharmalingam, R., Aruna, S., *Development of Chemical Protective Clothing Using Multilayer Fabric for Hazardous Chemicals Handling*, In: Journal of Natural Fibers, 2022, 19, 4, https://doi.org/10.1080/15440478.2020.1764450

[16] Eryuruk, S.H., *Effect of Fabric Layers on Thermal Comfort Properties of Multilayered Thermal Protective Fabrics*, In: Autex Research Journal, 2019, 19, 3, https://doi.org/10.1515/aut-2018-0051

[17] Alfaleh, A., Benltoufa, S., Fayala, F., *Evaporation coefficient determination during the capillary rise*, In: Textile Research Journal, 2023, 93, 17–18, 4191–4196, https://doi.org/10.1177/00405175231168425

[18] Benltoufa, S., Boughattas, A., Fayala, F., Alfaleh, A., Hes, L., Aljuaid, A., *Water vapour resistance modelling of basic weaving structure*, In: The Journal of the Textile Institute, 2024, 115, 12, 2456–2468, https://doi.org/10.1080/00405000.2023.2293503

[19] Benltoufa, S., Fayala, F., *The effect of Knit Materials Structural Parameters on the Adiathermic Property*, In: The International Journal of Applied Research on Textile, 2017, 5, 2, 26–35

[20] Benltoufa, S., Fayala, F., BenNasrallah, S., *Capillary Rise in Macro and Micro Pores of Jersey Knitting Structure*. In: Journal of Engineered Fibers and Fabrics, 2008, 3, 3, 155892500800300, https://doi.org/10.1177/155892500800300305

[21] Boughattas, A., Benltoufa, S., Fayala, F., *Moisture Management Properties of Double Face Denim Fabrics*, In: International Journal of Applied Research on Textile (IJARTEX), 2019, Special Issue CIRAT-8, 38–43

[22] Chakroun, M.G., Benltoufa, S., Fayala, F., *The effect of fabric's structure on the breathability and the drying rate Properties*, In: Communications in Development and Assembling of Textile Products, 2021,2, 1, 61–69, https://doi.org/10.25367/cdatp.2021.2.p61-69

[23] Boughattas, A., Benltoufa, S., Azeem, M., Hes, L., Fayala, F., *Thermo-physiological comfort of brushed woven fabrics*, In: Vlakna a Textil, 2018, 25, 3, 7–12

[24] Matsumura, H., Mishiro, M., Takachi, M., Ohdaira, K., *Super water-repellent treatment of various cloths by deposition of catalytic-CVD polytetrafluoroethylene films*, In: Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films, 2017, 35, 6, https://doi.org/10.1116/1.4999236

[25] Şimşek, B., Aslan, F., *Improvement of the Comfort Features of Denim Products*, In: The European Journal of Research and Development, 2022, 2, 4, https://doi.org/10.56038/ejrnd.v2i4.202

[26] Ruckman, J.E., *Water resistance and water vapour transfer*, In: Textiles in Sport, 2005, 287–305, https://doi.org/10.1533/9781845690885.4.287

[27] Ren, Y.J., Ruckman, J.E., *Water Vapour Transfer in Wet Waterproof Breathable Fabrics*, In: Journal of Industrial Textiles, 2003,32, 3, 165–175, https://doi.org/10.1177/1528083703032003002

[28] Ruckman, J.E., *The application of a layered system to the marketing of outdoor clothing*, In: Journal of Fashion Marketing and Management, 2005, 9, 1, 122–129

[29] Hes, L., *Alternative Methods of Determination of Water Vapour Resistance of Fabrics by Means of a Skin Model*, In: European Conference on Protective Clothing, Gdynia, 2006, 8, 10–12

[30] Yang, Y., Yu, X., Chen, L., Zhang, P., *Effect of knitting structure and yarn composition on thermal comfort properties of bi-layer knitted fabrics*, In: Textile Research Journal, 2021, 91, 1–2, https://doi.org/10.1177/0040517520932557

[31] Sahu, P., Gupta, M.K., *Water absorption behavior of cellulosic fibres polymer composites: A review on its effects and remedies*, In: Journal of Industrial Textiles, 2022, 51, 5_suppl, 7480S-7512S

[32] Alomayri, T., Assaedi, H., Shaikh, F.U.A., Low, IM., *Effect of water absorption on the mechanical properties of cotton fabric-reinforced geopolymer composites*, In: Journal of Asian Ceramic Societies, 2014, 2, 3, 223–230, https://doi.org/10.1016/J.JASCER.2014.05.005

[33] Benltoufa, S., Fayala, F., Nasrallah, S.Ben., *Determination of yarn and fiber diameters after swelling using a capillary rise method*, In: Journal of the Textile Institute, 2012, 103, 5, 517–522, https://doi.org/10.1080/00405000.2011.589573

Authors:

SOFIEN BENLTOUFA[1], HIND ALGAMDY[2]

[1]Laboratory for the Study of Thermal and Energy Systems (LESTE, LR99ES31), National Engineering School of Monastir, University of Monastir, Tunisia, 05000, Monastir, Tunisia

[2]Taif University, Turabah University College, Fashion Design and Fabric Department, Taif, Saudi Arabia
e-mail: h.saeed@tu.edu.sa

Corresponding author:
SOFIEN BENLTOUFA
e-mail: benltoufa@gmail.com