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OPTIMIZING ATHLETE'S COMFORT AND PERFORMANCE: INVESTIGATING LIQUID PERMEABILITY AND DRYING TIME IN SPORTS MATERIALS USING INFRARED THERMOGRAPHY

Antonija Petrov, Goran Cubric & Ivana Salopek Cubric

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Abstract

Determining the fluid permeability of sportswear is crucial for optimizing the comfort and performance of athletes during physical activities. This scientific study aims to investigate the absorption and drying processes of sports materials to gain insights into the dynamics of moisture management in sportswear. Infrared thermography will be used to monitor the drying process over time, providing a non-invasive and efficient method to evaluate material properties. Precise measurements and analysis will help identify materials that absorb liquid efficiently and dry quickly to reduce athlete discomfort during intense training or competition. This research is of paramount importance as it enables the development of sportswear that maximizes comfort and allows athletes to perform at their best without being hindered by moisture in the material.

Keywords: permeability; sportswear; absorption; drying; infrared thermography.

1. Introduction

Regular physical activity is crucial for maintaining good health. In order to achieve a high level of comfort and functionality during various sports activities, athletes today prefer high-performance sportswear [1]. Sportswear can be classified by the level of physical activity into active sportswear and sportswear for leisure [2]. Active sportswear is worn by professional athletes during certain shorter periods of activity. These sports require a high level of physical activity and maximum physical performance, which also leads to heavy sweating. Active sportswear should have optimal thermal and moisture management properties to maintain the thermal balance between the metabolic heat generated by the physical activity and the external environment. Sweat should be wicked away quickly to ensure a dry microclimate next to the skin. This requirement can be met by designing sportswear with low resistance to heat transfer and evaporative heat loss. Sportswear should allow rapid fluid transfer through absorption and have good drying properties to prevent condensation of liquid sweat close to the skin [2].

When the body produces sweat, the feeling of wet clothes is one of the main causes of discomfort. This can be caused by excessive sweat accumulation on the body, as the ability to wick away sweat is limited. Low or no moisture transport causes the body to become wet, resulting in an uncomfortable feeling as the clothing sticks to the wearer's body [3]. Absorption is the transfer of liquid through textiles by capillary action [4]. The absorption properties depend on the type of fibre, the yarn construction, the fabric structure, the density and texture of the yarn, the finishing processes, the viscosity, the relative humidity and the ambient temperature [5], [6]. The capillary channels in the spaces between the fibres and the pore size have a decisive influence on absorption [7].

Sportswear is usually made from polyester, polyamide and combinations with elastane. The literature states that 2% elastane is sufficient to improve the elasticity of the material and maintain its shape. However, in high-performance clothing such as swimsuits and sportswear, the elastane content can increase to 30% [8]. The ability of a material to dry depends on the amount of perspiration of the wearer and environmental factors such as wind speed, relative humidity and temperature [9]. To provide a better environment for athletes, it is important that the materials used in active sportswear quickly wick sweat away from the skin once it has been absorbed [10]. The material dries as the sweat evaporates and the vapour then disperses into the air. The drying process involves two successive operations: wetting and drying [11]. Humidification is the initial process in which the liquid spreads through the fabric by displacing the air interface [11], [12]. Absorption is the capillary force of the fabric, which determines how quickly it can transfer the absorbed sweat to the outer surface. The evaporation process is also crucial, as it helps to release the sweat from the outer surface of the garment to the environment by mass diffusion. The temperature of the sweat in the fabric, the humidity of the air and the speed of the airflow all play a crucial role in how quickly the sweat molecules break down and evaporate [13]. Our previous research has highlighted the importance of the properties of polymeric knitted fabrics in relation to material aging [14] and the transfer of liquid and water vapour through the knitted materials [15]. Furthermore, a study focusing on improving the thermophysiological comfort of athletes through the thermographic evaluation of sportswear materials highlighted the importance of evaluating the absorption and drying processes to optimise the comfort and performance of athletes [16].

Based on the reviewed literature and the outlined requirements for high-performance sportswear, the heat and moisture management properties of different knitted fabrics are evaluated in the experimental part of this study. The focus is on the comparison of polymer materials with and without elastane component, and even more on the comparison of conventional and recycled materials. The reason for this is that the use of recycled materials in sport offers considerable potential for promoting sustainability, achieving economic benefits and fostering innovation. However, the number of studies on this segment has not yet been sufficiently researched, leaving a niche for further research. In the experiment presented in this paper, the absorption and drying rates of artificial sweat on different fabric samples are measured and the data analysed to determine their suitability for high-performance sports activities. The aim is to identify fabric characteristics that ensure optimal comfort by efficiently managing sweat dispersion and evaporation.

2. Materials and methods

2.1. Materials

The materials selected for this study are listed in Table 1. This table gives raw material composition and yarn fineness of the materials tested. The selected materials are different blends of conventional polyester (PES) and elastane (EL) as well as fabrics made from 100% recycled polyester. These differences in composition and structure are analysed to assess their impact on the absorption and drying properties that are essential for high-performance sportswear.

Material ID	Yarn properties	
	Composition	Yarn fineness, tex
P1	100% PES	12
P2	100% PES	10
P3	84% PES + 16% EL	10
P4	87% PES + 13% EL	10
P5	100% PES, recycled yarn	10
P6	100% PES, recycled yarn	10

Legend: PES - polyester, EL - elastane

Table 1. Material description

2.2. Methods

The following properties of the knitted fabrics were analysed: mass per unit area, thickness, stitch density as well as the absorption and drying process of knitted materials intended for sportswear.

The mass per unit area of the knitted fabrics was determined using a Kern ALJ 220-4 analytical balance with an accuracy of 0.00001 g in accordance with the ISO 3801 standard [17]. To measure the mass per unit area, the samples were cut to 100x100 mm. Each sample was weighed five times and the average value of these measurements was calculated. The thickness of the materials was measured using a DM-2000 thickness gauge by Wolf Messtechnik GmbH. During the measurements, a pressure of 1 kPa was applied to an area of 20 cm² of the sample. This test was carried out in accordance with the ISO 5084 standard [18]. A total of 10 measurements were taken at different points on each sample. The thickness measurement points were located in the centre of the sample and along the diagonal (starting from the left corner of the sample). The average thickness was expressed as the mean of these 10 measurements.

The stitch density represents the number of stitches per unit area. It is obtained by the following equation:

$$D_o = D_h \cdot D_v \quad (1)$$

where: D_o - stitch density (stitch/cm^2), D_h - horizontal density, D_v - vertical density.

The horizontal (Dh) and the vertical (Dv) density were determined using a Dino-Lite Edge AM7915MZT digital microscope. Image analysis was performed using the professional software DinoCapture 2.0. The absorption and drying process of the materials were tested as follows: knitted fabric samples with dimensions of 30x30 cm were placed in metal frames (29x29 cm) and elevated above the work surface. Using a pipette, 1 ml of artificial sweat (acidic sweat powder with pH 5.5, prepared according to BS EN ISO 105-E04 [19]) was applied to each sample (Fig. 1). The liquid that passed through the material was collected in plastic cups placed underneath the samples. The amount of liquid that passed through the material and accumulated in the cups was measured using an analytical balance. The difference between the initial amount of liquid (1 ml) and the measured amount in the cup allowed for the calculation of the amount of liquid retained on the surface of the material. In addition, the drying process of the materials was monitored using a TESTO 872 infrared thermographic camera (Fig. 2).

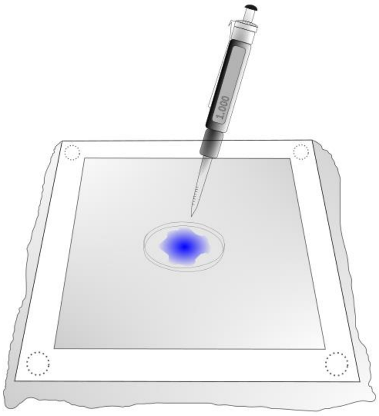

Fig. 1. Application of test liquid on knitted material using a pipette

Fig. 2. Drying process monitoring with an infrared thermographic camera

3. Results and discussion

The results of knitted fabric properties testing, including the mass per unit area, thickness and stitch density are shown in Table 2.

Material ID	Fabric properties		
	Mass per unit area, g/m^2	**Material thickness, mm**	**Stitch density, stitches/cm^2**
P1	155	0.618	360
P2	151	0.491	272
P3	180	0.451	888
P4	141	0.351	1175
P5	130	0.451	289
P6	185	0.629	441

Table 2. Results of fabric properties testing

The experimental data show the relationships between the mass per unit area, thickness and stitch density of the knitted materials and their liquid absorption and transmission properties. The material P4 with the highest stitch density of 1175 stitches/cm² absorbs a considerable amount of liquid (0.50752 ml), while 0.49248 ml is transferred into the cup (Fig. 3). This suggests that a higher stitch density can balance both absorption and transfer, providing a denser structure that improves moisture retention and controlled transfer. In contrast, material P5, which is relatively thin (0.451 mm) and lightweight (130 g/m²) and has a low stitch density of 289 stitches/cm², had the highest permeability (0.82459 ml) and the lowest absorption (0.17541 ml). This suggests that a lower stitch density combined with a lighter and thinner fabric allows for faster drying and better liquid permeability, making it suitable for applications where fast moisture management is critical. Material P6, the thickest (0.629 mm) and with the greatest mass per unit area (185 g/m²) of the samples, with a moderate stitch density of 441 stitches/cm², retained a considerable amount of liquid (0.49086 ml) but also allowed a considerable amount of it to pass through (0.50914 ml). This balance suggests that thicker materials with a greater mass per unit area may retain a significant amount of moisture but are also able to allow some of the liquid to pass through, potentially contributing to longer wearer comfort by effectively wicking sweat away.

In summary, the results suggest that fabric structure, particularly stitch density, plays a crucial role in determining the moisture management properties of knitted sportswear. Fabrics with a high stitch density, such as P4, are better at wicking away moisture and keeping the skin dry, which increases comfort during low to moderate activity. On the other hand, fabrics such as P5 with a lower stitch density and lighter mass per unit area, are better suited to high-intensity activities where rapid moisture wicking and evaporation are important. The choice of fabric should therefore be tailored to the specific performance requirements of the sportswear and strike a balance between absorption and permeability to optimise the athlete's comfort and thermoregulation.

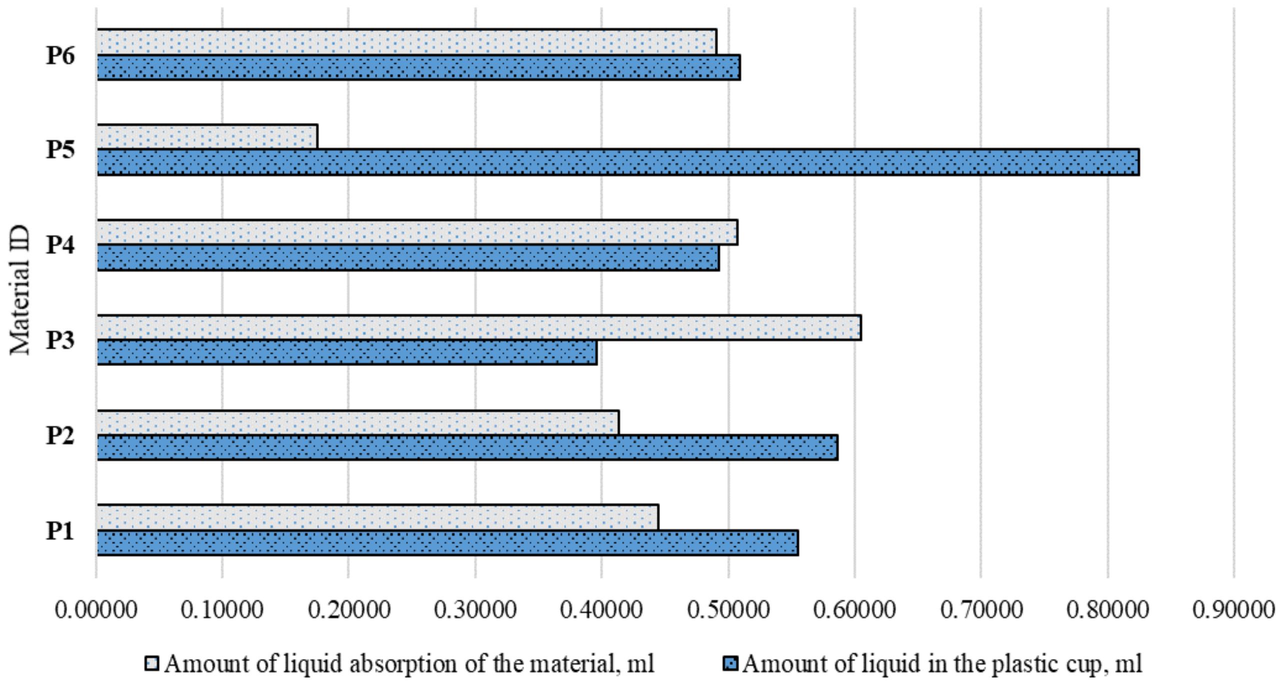

Fig. 3. Distribution of liquid absorption of the material and amount of liquid in the plastic cup

The analysis of the wetting and drying properties is shown in Figure 4. Material P2 is characterised by the fastest wetting time (5.16 seconds) and the highest wetting speed (12.53 mm/s along the y-axis), indicating excellent initial moisture absorption. This material also has a large surface (2608.2 mm²), which indicates that it can wick away moisture quickly. Despite its efficient absorption, P2 has a moderate drying time (1.01 hours), which is related to its relatively low mass (151 g/m²) and moderate thickness (0.491 mm). The stitch density of 272 stitches/cm² enables effective moisture management through a balance between absorption and evaporation. This makes P2 a strong candidate for high performance sportswear where fast moisture management is crucial. On the other hand, material P6 has the slowest wetting time (13.20 seconds) and the lowest wetting speed (2.79 mm/s along the y-axis), indicating less efficient initial moisture absorption. However, it also has the smallest surface (785.8 mm²), which could contribute to faster saturation and slower spread of moisture. P6 also has the longest drying time (1.72 hours), which is due to its higher mass (185 g/m²) and thickness (0.629 mm). These properties suggest that P6 is better suited to cooler climates or less intense activities where prolonged moisture absorption is less important. While material P5 has the highest amount of liquid in the plastic cup (0.82459 mL) and the lowest liquid absorption of the material (0.17541 mL), it also has a slow wetting time (9.87 seconds) and wetting speed (4.66 mm/s along the y-axis).

This material dries the fastest (0.75 hours) and benefits from its relatively low mass (130 g/m²) and moderate thickness (0.451 mm) with a stitch density of 289 stitches/cm². The performance of P5 underlines its suitability for high-intensity activities where quick drying and efficient moisture transport are crucial.

In summary, it can be said that the interaction of mass, thickness and stitch density decisively determines the wetting, absorption and drying behavior of knitted materials. Materials such as P2 (100% PES) with fast wetting and moderate drying time are ideal for active sportswear that requires fast moisture transport and evaporation. Conversely, materials such as P6 with slower wetting and longer drying time are more suitable for conditions where longer moisture absorption is acceptable. P5 (100% recycled PES), which dries quickly and has high permeability, offers excellent performance during intense activities. This underlines the need to select materials based on specific sports and environmental requirements.

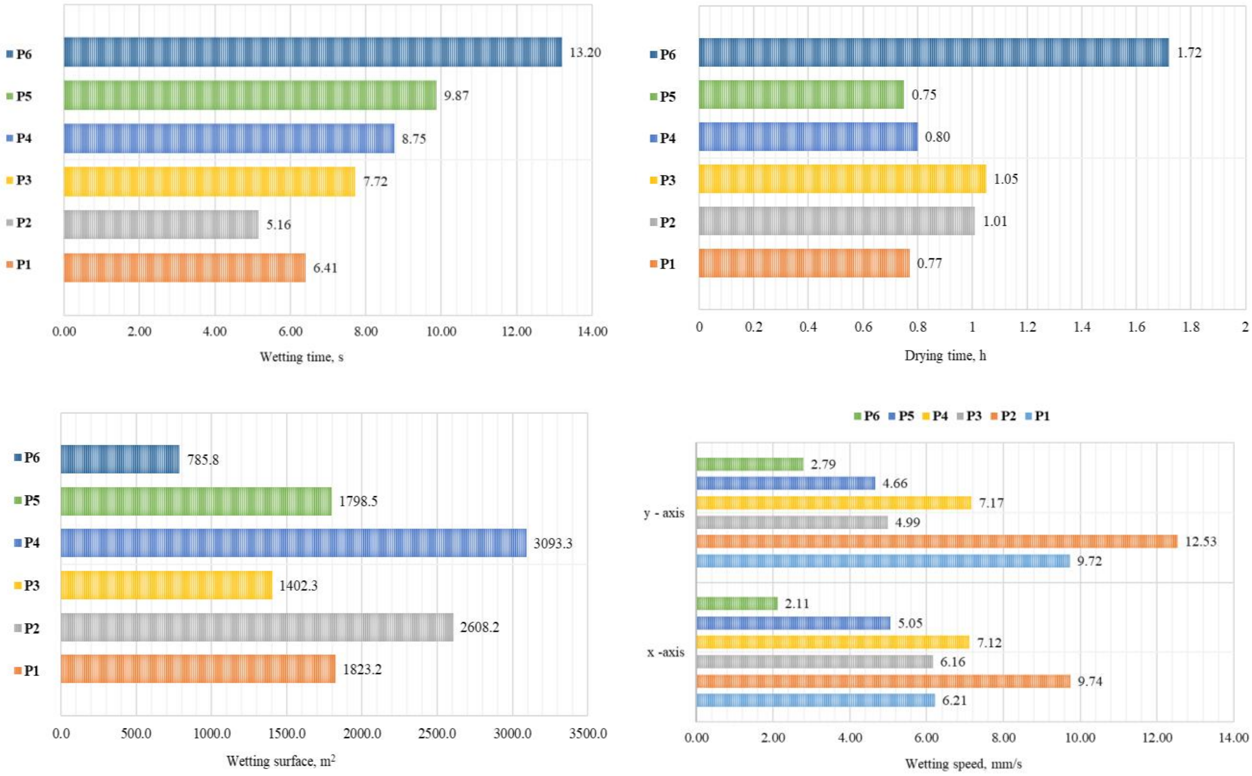

Fig. 4. Results of wetting and drying characteristics of knitted materials - wetting time, drying time, wetting surface, and wetting speed

4. Conclusion

This study addressed the problem of identifying high-performance sportswear materials that optimise the athlete's comfort and performance during physical activity, in particular by improving moisture management. The problem was solved by analysing the absorption and drying processes of different sports materials, using infrared thermography to monitor the drying process over time. This method allowed a precise and non-invasive evaluation of the material properties. The results showed that materials P2 (100% PES) and P5 (100% recycled PES) are the most suitable for high-performance sportswear, as they have an optimal balance between efficient liquid absorption and fast drying, directly reducing athletes' discomfort during intense training or competition.

This study also provided a positive insight into the behaviour of recycled materials, which contrasts with some previous research that suggested otherwise. This emphasises the significant potential for wider application of recycled materials in the sports industry, particularly given the continuing advances in recycling technologies and the growing environmental awareness of consumers and manufacturers. This study had several limitations. These include the number of individual measurements for each sample, which, although sufficient for a preliminary analysis, could limit the generalisability of the results, and possible variations in standard atmospheric conditions during the tests, which could have affected the reliability of the results. In addition, infrared thermography, while accurate, is susceptible to variations in ambient temperature, which could affect the accuracy of the drying rate measurements. For the future, further research should focus on advanced fabric technologies and sustainable materials to continuously improve the functionality of sportswear. This study provides an important basis for the further development of sportswear that effectively wicks away moisture to improve the comfort and performance of athletes.

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