Wicking Performance of C-Shape Filament Yarn for Comfort Fabrics

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Abstract

Clothing has a huge impact on comfort and physiology when participating in sports such as running, cycling and hiking and other outdoor activities. Three factors—psychological, tactile, and thermo-physiological—can be used to categorize clothing comfort. Functional clothing, especially sports and activewear, needs to have fabric moisture management properties like sweat absorption, distribution, draining, evaporation and drying in order to work properly and be comfortable. The absorption, distribution, evaporation, and drying properties of synthetic textiles are significantly influenced by the rate of moisture dispersion, or wicking. Fibres in apparel can have an impact on the wearer's comfort. The primary goal of this research is to look at the effect of the C shape cross section filament yarn on the wicking ability of polyester fabric. In this study, the wicking ability of polyester filament yarn of circular cross sections compared with the C Shape cross sections filament yarn. The experimental results show that the C Shape filaments perform better in wicking tests than circular cross section filaments. The better wicking of C Shape filaments can be attributed to two factors: first, the increased surface area for capillary action, and second, the micro and liner capillaries created inside the C Shape cross section of the filament.

Keywords: *C-Shape Filament Cross Sections, Capillary Flow, Comfort, Profile Filament, Wicking*

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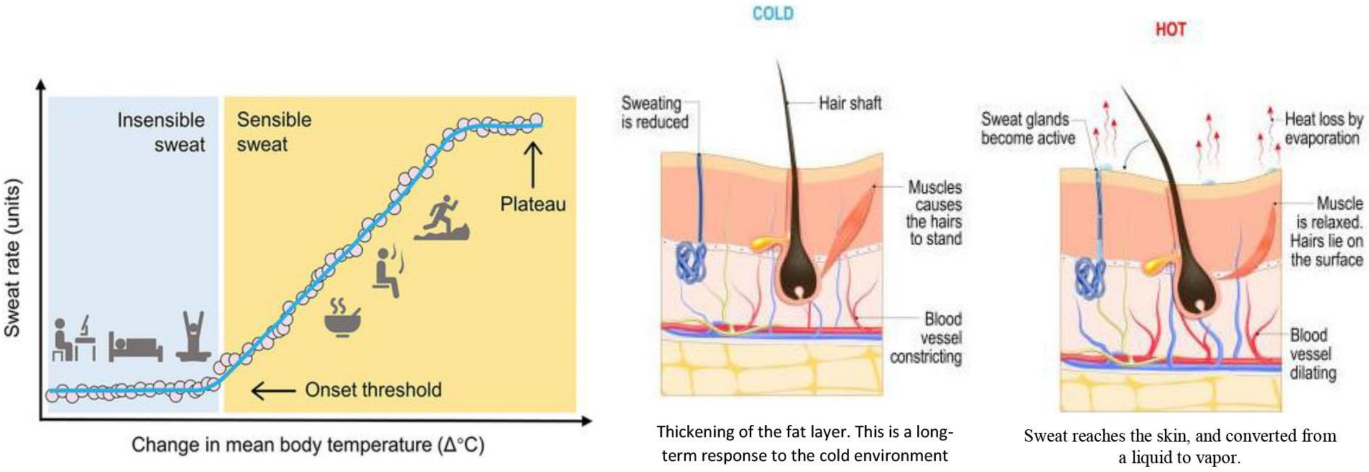
1. Introduction

Comfort is regarded as a critical component in the development of functional clothes. Various attempts have been made to evaluate and describe human garment comfort. Clothing is said to as a second skin, and it is quite vital in everyday life for feeling comfortable. Humans have acquired an interest in clothes for various activities such as jogging, hiking, and rock climbing in recent years, and are aware of its comfort and functionality [1].

The most significant aspect of clothing is its comfort, which can be divided into three categories: psychological, tactile, and thermo-physiological. Psychological comfort has nothing to do with fabric characteristics and is primarily determined by societal fashion trends. Tactile comfort is primarily determined by how much stress is generated in the fabric and how it is distributed across the skin, and it thus has a significant relationship with both mechanical and surface qualities of fabric. The fabric handle has a direct relationship to tactile comfort. Thermal comfort is related to the fabric's ability to maintain skin temperature and allow perspiration to be transferred from the body. Thermal resistance, air permeability, water vapour permeability, and liquid water permeability are recommended as crucial for a body's thermal comfort [1].

Fabric moisture management qualities, such as sweat absorption, distribution, evaporation, draining, and drying, are crucial to the performance and comfort of functional garments, particularly athletics and activewear. The rate of moisture dispersion, or wicking, has a significant impact on the qualities of synthetic textiles such as absorption, distribution, evaporation, and drying. Fabrics having a higher wicking rate absorb more moisture and transport it to a broader surface area, resulting in faster drying and higher comfort levels. As a result, the best wicking behaviour in fabrics is required to achieve clothing comfort, particularly in sportswear [2-4].



Thickening of the fat layer. This is a long-term response to the cold environment

Sweat reaches the skin, and converted from a liquid to vapor.

Figure 1: The relationship between change in mean body temperature and sweat rate with mechanism of body thermoregulation [5]

Figure 1 shows how the body's thermoregulation process affects the relationship between sweat rate and mean body temperature change. The main loss of physical sweat under the onset threshold is insensible sweat (office work, relaxing, yoga, etc.). After the onset threshold (running or high-intensity activity), liquid or visible sweat predominates. The optimal sweat rate peaks even if the body temperature climbs more. Sweating can cause some of the body's liquid and vapour (hygroscopic) fluids to be absorbed by clothing. Sweating evaporates from the skin or clothing, causing cooling [5].

1.1 Fibre parameters and thermo-physiological Comfort

By carefully choosing clothing material and construction specifications, the energy balance between the human body and environment required for physiological comfort is modified in a way that is beneficial, highlighting the fact that functions of clothing are crucial to man in all environments, especially extreme weather conditions [6].

Because of its beneficial characteristics, such as high strength, dimensional stability, ease of maintenance, and wrinkle-free qualities, polyester fibre is the most frequently and widely used fibre. However, 100% polyester and textiles rich in polyester are uncomfortable to wear due to their hydrophobicity. over the world, some initiatives have been made to get over this polyester limitation by altering the fibres' external forms. In this sense, fibre cross-sectional forms and fineness have been the main topics of research for fabric designers as they relate to wear comfort. Since polyester fibres have a poorer thermal conductivity than other fibre types, warmth is retained longer when the fibres are hollowed out or grooved [7, 8].

Particularly in wear scenarios when substantial sweating occurs, the lower dtex of microfibers showed to be physiologically favourable. Wetting and wicking is the most efficient method for preserving a comfortable feeling in sweaty conditions. When wearing clothing with strong wicking abilities, moisture from the skin is dispersed throughout the material, leaving the wearer feeling dry and facilitating quick evaporation of moisture [9].

One of the most important aspects of a textile is how it reacts to water or liquid in general. Wetting of fibre materials can have a considerable impact on both the performance of materials after ultimate use and multiple production processes. Liquid moisture flows through textiles due to fabric-liquid molecular attraction at the surface of the fibre materials, which is principally determined by surface tension and effective capillary pore distribution and pathways. Wetting and wicking are two mechanisms that allow liquid to pass through a porous surface in a sequential manner. Wetting is the first step in the diffusion of a fluid. In this technique, the fiber-liquid interface replaces the fiber-air interface.

$$\gamma_{SV} \;\; - \gamma_{SL} \; = \gamma_{LV} \cos\theta \ldots\ldots (1)$$

Here, y represents the tension at the interface between the various combinations of solid (S), liquid (L) and vapour (V), and θ is the contact angle between the liquid drop and the surface of the solid to be wetted.

In this equation, y represents the tension at the interface of various solid (S), liquid (L), and vapour (V) combinations, and θ is the contact angle between the liquid drop and the surface of the solid to be wetted.[10], [11] Direct correlation exists between the contact angle and the fabric's wetability. The degree of wettability is high when there is little contact between the fibre and the liquid. When the apparent wetting angle decreases with increasing surface roughness, it is because of the troughs that rough surfaces produce that water spreads across the surface more quickly. Because the surface's chemical composition influences the wettability of the substance, as hydrophilicity increases, the contact angle decreases and surface wettability increases.

The best method for retaining a comfortable feeling when perspiring is wicking. When wearing clothing with strong wicking abilities, moisture from the skin is dispersed throughout the material, leaving the wearer feeling dry and facilitating quick evaporation of moisture. The capillary pressure is created when the liquid penetrates the gaps between the fibres and wets them. The meniscus's curvature in the tiny spaces between the pores causes the liquid to be driven by this pressure and dragged along the capillary. Wickability is the capacity to maintain capillary flow. The Laplace Equation 2 provides the capillary pressure's magnitude.

$$P_c = \frac{2\pi r \gamma_{LV} \cos\theta}{\pi r^2} = \frac{2\gamma_{LV} \cos\theta}{r} \quad \ldots\ldots\ldots\ldots (2)$$

The capillary pressure created in a capillary tube with a radius of r is denoted by P_c in the above formula. The distribution of the fluid in the media is caused by a variation in capillary pressure in the pores. Since the pressure inside the capillary is higher the smaller the pore size, the earlier it fills. The smaller holes are the last to empty during capillary draining under external pressure. Only capillary forces may be responsible for the movement of liquid into a fibrous construct, as a yam or cloth. Liquid is drawn into the gaps between the capillaries by capillary forces. Yarns and textiles have different capillary gaps. Additionally, the surfaces and pore walls of fibrous materials have roughness [10-12].

Even though it doesn't spread over the smooth surface of the same solid, a liquid can spread along ridges or rugosities on a surface. The driving force behind this surface wicking depends on the geometry of the grooves, the liquid's surface tension, and the free energies of the solid-liquid and solid-gas interfaces. When discussing capillary flow in fabrics theoretically, fibrous assemblies are typically thought to be made up of many parallel capillaries. In a non-homogeneous capillary system, such a fibrous construction, the liquid moves discontinuously.

The uneven capillary gaps' varying diameters induce the wetting front to enter the capillary system in tiny jumps. The pace of wicking is crucial because the majority of textile processes have time constraints. However, there are other elements besides interfacial tensions and fibre wettability that can affect the wicking rate. The capillary dimensions of the substrate, which rely on the shape and geometry of the fibres, determine the wicking rate [13-15].

For capillary action to occur, the cumulative pressure inside the capillary tube must be greater than liquid gravity. The related expressions are those found in equation (3).

$$\frac{2\gamma_{LV} \cos\theta}{r} \pi r^2 - \pi r^2 h \rho g > 0 \quad \ldots\ldots\ldots (3)$$

Where h, r, g, and ρ stand for the capillary liquid height (m), equivalent capillary radius (m), gravity acceleration (m/s2), and liquid density (kg/m3), respectively. likewise θ theta and γ_{LV} represent the liquid-gas contact angle and liquid-vapor interfacial tension, respectively, at 20 °C, where water has a value of 0.0725 (N/m).

$$h = \frac{2\,\gamma_{LV} \cos\theta}{r\rho g} \quad \ldots\ldots\ldots (4)$$

The greater the capillary equivalent radius, the smaller the wicking height (h). [12], [13]By modifying cross sections, creating micro cross sections, and improving yarn compactness, the capillary's radius may be reduced. The influence of C Shape cross section on the wicking behaviour of polyester filament yarn is examined in the current study in comparison to filament yarns with circular cross sections.

2. Materials and Methods

On the melt spinning apparatus seen in figure 2, the Bombay Textile Research Association lab in Mumbai created the polyester filament yarns with circular and C-shaped cross-sections. The number of filaments and the diameter of the filaments were maintained for both circular and C-shaped cross-sections. The information on spinneret profiles and the manufacturing process parameters are provided below.

Figure 2: The pilot melt spinning machine used to develop filaments yarns

2.1 Manufacturing process parameters

- Melt Spinning – Textile Equipment Co. Delhi
- Spinning Temp- 220 °C
- 195,210 and 215 °C of 3 Heater

To estimate the filament diameter and cross-section form, the yarn samples are measured using an electronic microscope. The observed C-shaped filament yarn sample is displayed in a microscopic view.

Figure 3: Microscopic image of the C Shape filament yarn

The average diameter of round and C-shaped filaments measured under a microscope at ten different locations for each filament. The occurrence of Hollo open voids in the cross sections, like to the letter "C" in the alphabets, gives C-shaped cross sections their name. Filaments with solid circular cross sections are depicted in these cross sections. Table 1 lists the specifics of the properties assessed on the yarn.

Table 1 - The dimensions of cross-section of the round and C shaped filament yarns

Sr. No	Number of Filaments	Diameter of Circular Cross-section Filaments	Dimensions of C Shape Cross-section Filaments			
			Outer	Inner	θc	Thickness of C Curve
Sample 1	35	0.07 mm	0.07 mm	0.04 mm	30°	0.015 mm
Sample 2	35	0.09 mm	0.09 mm	0.06 mm	30°	0.015 mm
Sample 3	35	0.11 mm	0.11 mm	0.09 mm	30°	0.02 mm
Sample 4	35	0.13 mm	0.13 mm	0.11 mm	30°	0.02 mm

2.2 Vertical Wicking Test of Yarn Samples

The vertical wicking height of all eight samples was measured with regard to time using a vertical wicking test setup as shown in figure 4. All four samples of same cross section tested for wicking performance together, using the experimental setup with a frame on which yarns are hold with uniform tension. The entire process, from the start of the wicking process to the water reaching equilibrium in the yarn, has been documented. To improve the visual clarity of the flow, 3 g/l Procion blue reactive dye was added to the water used in the experiment.

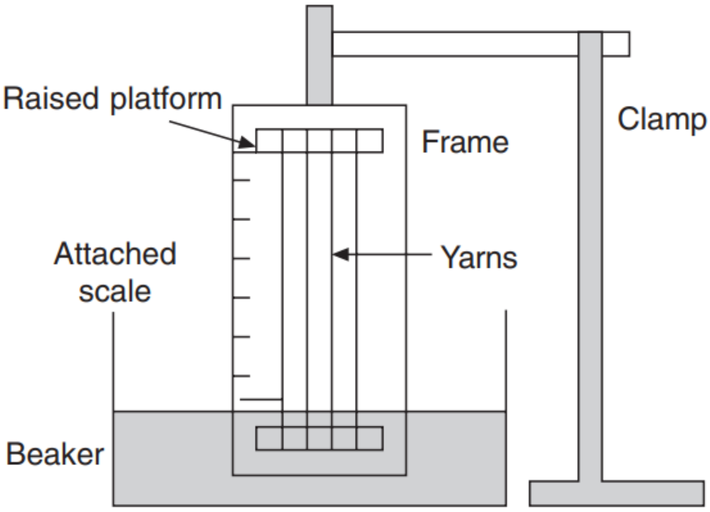


Figure 4: Experimental setup for yarn vertical wicking test.[16]

3. Results and Discussion

Tables 2 and 3 demonstrate the maximum wicking heights of filament yarns with circular cross sections and C shape cross sections determined from the experimental data. It indicates that, i) for both circular and C Shape filaments, finer filaments have a higher maximum wicking height than coarser filaments. ii) Circular filament yarns have a lower maximum wicking height than C shape filament yarns of the same outer diameter.

Table 2 - Maximum Wicking Height of circular filament yarn

Sr. No	Number of Filaments	Diameter of Circular Cross-section Filaments	Maximum Wicking Height mm
Sample 1	35	0.07 mm	44
Sample 2	35	0.09 mm	40
Sample 3	35	0.11 mm	34
Sample 4	35	0.13 mm	31

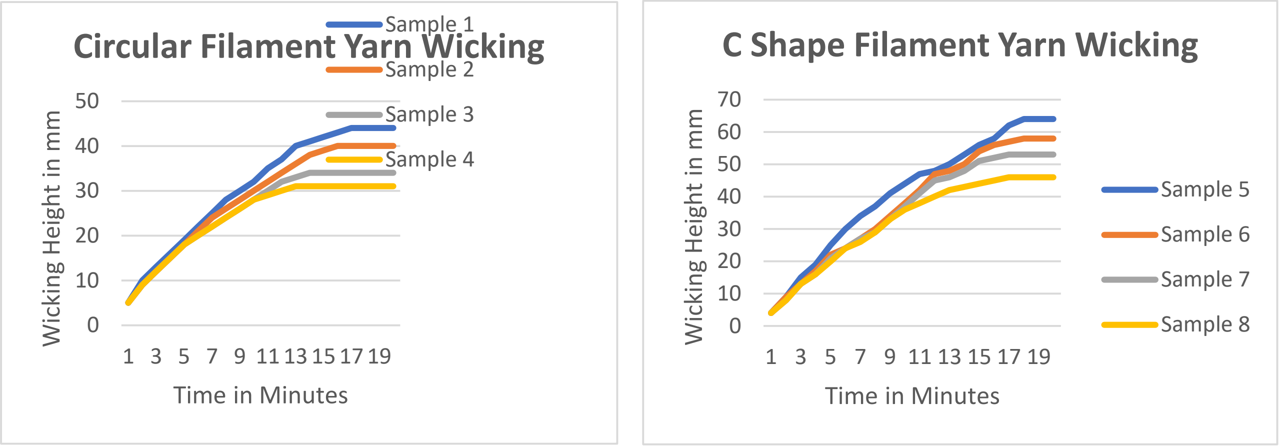
Table 3 - Maximum Wicking Height of C Shape filament yarn

Sr. No	Number of Filaments	Dimensions of C Shape Cross-section Filaments				Maximum Wicking Height mm
		Outer Diameter	Inner Diameter	θc	Thickness of C Curve in	
Sample 5	35	0.07 mm	0.04 mm	30^o	0.015 mm	64
Sample 6	35	0.09 mm	0.06 mm	30^o	0.015 mm	58
Sample 7	35	0.11 mm	0.09 mm	30^o	0.02 mm	53
Sample 8	35	0.13 mm	0.11 mm	30^o	0.02 mm	46

First observations about higher wicking height in finer filaments have already been published in study journals by several researchers. Finer filaments generate finer capillaries in the yarn structure, resulting in higher wicking height in finer filaments than coarser filaments. This is true for both circular and C-shaped filament yarns.

The second finding shows that C-shaped filaments wick more effectively than circular filaments. This is because the C-shaped filaments have a bigger surface area where wicking capillaries can form. As illustrated in figure 3, yarn with circular filaments forms capillaries with the outer borders of the filaments near to one another, in contrast to C shape filaments, which form capillaries with both the inner core and the outer boundaries of the filaments adjacent to one another.

Figure 5 depicts the wicking behaviour of the C shape and circular cross section filament yarns as seen in the vertical wicking experimental test of the filament yarns. All four samples' observed wicking heights in circular filaments are identical up to 6 minutes, at which point sample 1's finer filaments continue to wick at the same rate for an additional 17 minutes. The sample 2 continues to wick at a somewhat slower rate than the sample 1 does up to a 15-minute mark. Both samples 3 and 4 exhibit a similar wicking pattern, however at a slower rate that lasts for 13 and 10 minutes, respectively.



(a) **(b)**

Figure 5: Graphical representation of wicking height for a) Circular cross section filament yarn and b) C Shape cross section filament yarn

The circular filament in sample 1 has an outer diameter of 0.07 mm, and when compared to the C-shaped cross-section filament in sample 5, which has an outer diameter of 0.07 mm, the wicking behaviour shows that both filaments have the same outer diameter, but the C-shaped cross-section filament provides continuous wicking rate for a longer period of time than the circular filament. After 5 to 7 minutes, the wicking rate in circular filaments slows down, and the maximum wicking height is reached after another 11 to 14 minutes of wicking. Wicking proceeds at a constant rate in the C-shaped circular filaments until the maximum level of wicking is reached. Due to continuous capillary that has formed inside the C Shape, the filament in this shape is continuous. As a result, water can rise until the acceleration brought on by gravity acting on the water molecule equalises the capillary pressure. However, in the case of circular filaments, the walls of the adjacent filaments serve as capillaries. These capillaries vary in diameter depending on where they are located, and because of twist or torsion, they shift direction at an angle from the yarn axis. Circular filaments exhibit a decrease in vertical wicking rate after a given height due to the capillaries' altered axis, which causes wicking to occur less precisely in the vertical direction.

4. Conclusion

The experimental investigation to determine the influence of their cross sections, i.e. circular and C shape, on wicking behaviour. Filaments with C shape cross sections have a higher maximum wicking height as well as wicking rate than the circular filaments. In comparison to the C Shape filaments, this reduced the wicking performance of the circular filaments. According to the findings of this study, C shape filaments have greater wicking ability than circular filaments and can thus be utilised in sportswear materials where a higher wicking rate for sweat spreading is required. The rapid distribution of perspiration across the cloth provides a vast surface area for sweat evaporation into the atmosphere, resulting in rapid drying. This fast spreading, evaporation, and drying of perspiration results in increased fabric comfort.

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