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Thermal comfort properties of natural and manmade cellulosic fabrics

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A crucial and expected characteristic of a fabric chosen for garment purposes is its capacity to transport and evaporate moisture efficiently. The current study evaluates the thermal comfort characteristics of four distinct natural and synthetic cellulosic fibres, their blends, and modifications made to three different knitted structures. The results demonstrate that modal fibre distributes and wicks swiftly, taking 50% less time on average than other fibre samples. Single jersey fabrics excelled the other two structures in exhibiting thermal characteristics. For applications like sportswear, where enhanced thermal comfort with improved quality are required, single jersey modal fabric is evaluated as a superior thermal comfort fabric.

Keywords: Comfort, Knitted structure, Modal, Single jersey, Thermal comfort

1 Introduction

One of the primary factors influencing a consumer's perspective on clothing is comfort, or the perception of warmth or coolness[1]. Stitch length, along with parameters like flexibility, moisture diffusion, linear density, thermal comfort, etc., can simultaneously influence the comfort properties of clothing materials[2].

Postle[3] demonstrated how the effective yarn diameter and loop curvature are related to the thickness of knitted materials. Ramachandran *et al*.[4] examined the relationship between the physical properties of knitted materials and their thermal behaviour. Their study showed that fabric attributes including thickness, tightness factor, aerial density, and air permeability, affect knitted materials' thermal conductivity, diffusion, and resistance to heat. Comfort is a crucial aspect of clothing, greatly influencing consumers' decisions when selecting their wardrobe. Priyalatha *et al.*[5] emphasized the area of liquid spread was increased when the percentage of deformation increased. Knit textiles have long been popular across various apparel types because of their exceptional comfort features. Knits offer lightweight warmth, wrinkle resistance, and simplicity of care in addition to the comfort that its extendable looped structure imparts.

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After analysing the mechanical characteristics of bamboo fibre, Okubo *et al*.[6] concluded that its strength is comparable to that of glass fibre. Air permeability of the fabric depends on the variations in linear density of the yarn in fabric layers, fabric thickness and fabric weight[7]. According to Dundar[8], knitted fabrics made entirely from bamboo have greater friction strength than those made entirely from cotton.

The fabric hand characteristics of bamboo, cotton, and cotton/bamboo fabrics were examined by Grineviciute *et al*.[9]. The outcomes were the same for both finished and unfinished fabrics. In comparison to cotton, bamboo fibre offered garments with superior hand qualities. Gun *et al*.[10,11] evaluated the volumetric and physical characteristics of simple knitted fabrics made from a combination of 50/50 viscose and cotton with those of 50/50 modal and bamboo yarn. They concluded that the texture of fabrics made from these three yarns was comparable. The weight, thickness, bursting strength, air permeability, and pilling of the textiles were all examined and it was found that these characteristics were unaffected by the fibre type.

The absorption and evaporation behavior of fabrics varies with fabric areal density, which becomes critical during active sports where the body generates sweat to regulate core temperature. The excessive sweat retention in garments leads to a damp and clingy sensation[12,13]. The sports and leisure wear act as barriers to effective heat transfer, disrupting body thermoregulation and resulting in elevated core body and skin temperatures, ultimately leading to sweating[14].

Thermal comfort is one of several factors that influence clothing comfort. The primary determinants of thermophysiological comfort are fibre type, yarn properties, fabric structure, finishing techniques, and clothing factor. The main objective of this study is to systematically evaluate the effects of different cellulosic fibre types and their blends on the thermal comfort characteristics of textiles, with an emphasis on cotton, bamboo, modal, and tencel. This study explores the contributions of these fibres to water vapour permeability, thermal conductivity, air permeability, and thermal resistance, providing insights into their suitability for maintaining comfort.

2 Materials and Methods

2.1 Materials

The 30s count yarns were acquired from the local market and included 100% cotton, 100% bamboo, 100% modal, 100% tencel, 50% cotton:50% bamboo, 50% cotton:50% modal, and 50% cotton:50% tencel. All seven of these yarns were used to construct the three knitted constructions shown in Fig. 1 namely, single jersey (knit), single pique (knit and tuck), and honey comb (knit and float).

To evaluate the fabrics' ability to control moisture, knitted fabrics were made using a Mayer and Cie knitting machine with a 24 inch gauge, 24 inch diameter, 72 feeders, and a loop length of 3.0 0.1mm. Table 1 lists the fabric's technical specifications. All of the produced samples are collected for further analysis after being allowed to rest for 24 hours under typical atmospheric conditions.

2.2 Methods

2.2.1 Air Permeability

Air permeability refers to the ability of a material to allow air to pass through it, which is determined by measuring the ease of air movement through the fabric under a pressure differential. The KES-F8 AP1 Air Permeability Tester was used in accordance with British Standard BS 5636:1990 to assess the air permeability of fabrics made from various fibre combinations and structures.

2.2.2 Thermal Conductivity

The fabrics' thermal conductivity was ascertained using Lee's disk instrument, in accordance with the ASTM D7340 standard. Thermal conductivity is an important property that indicates the amount of heat transferred through a fabric under a given temperature gradient. Another important metric is the thermal resistance (R), which is calculated using the formula:

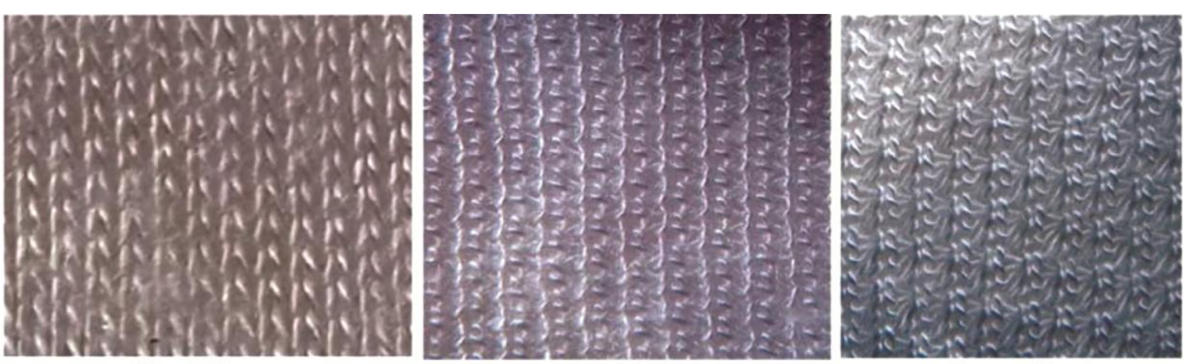
$$R = h / \lambda \ (m^2K/W)$$

where λ is the thermal conductivity (W/mK); and h, the fabric thickness (m).

2.2.3 Water Vapour Permeability

The water vapour permeability of the fabric was evaluated according to British Standard BS 7109:1990. This method involved covering the open mouth of a standard test dish filled with water with fabric samples and placing the dish in a controlled setting for one hour, with a temperature of 20°C and 65% relative humidity. The weight of each fabric sample was determined following each cycle, providing insight into fabrics’ water vapour permeability.

The manufactured fabrics were put through a series of standard tests to determine their thickness (per ASTM D 1777), areal density (per ASTM D 3776),



Single Jersey Single Pique Honey Comb

Fig. 1 — Image of fabrics produced from different knitted structure

Table 1 — Specifications of fabrics used

S. No.	Sample code	Fibre type	Structure	Thickness, mm	Areal density, gsm
1	CHC	100% Cotton	Honey comb	0.116	180
2	CSP	100% Cotton	Single pique	0.036	140
3	CSJ	100% Cotton	Single jersey	0.042	150
4	BHC	100% Bamboo	Honey comb	0.922	170
5	BSP	100% Bamboo	Single pique	0.762	158
6	BSJ	100% Bamboo	Single jersey	0.721	130
7	C/BHC	50% Cotton- 50% Bamboo	Honey comb	0.848	150
8	C/BSP	50% Cotton- 50% Bamboo	Single pique	0.874	140
9	C/BSJ	50% Cotton- 50% Bamboo	Single jersey	0.536	156
10	MHC	100% Modal	Honey comb	0.452	137
11	MSP	100% Modal	Single pique	0.304	126
12	MSJ	100% Modal	Single jersey	0.272	120
13	C/MHC	50% Cotton − 50% Modal	Honey comb	0.674	194
14	C/MSP	50% Cotton − 50% Modal	Single pique	0.404	141
15	CMSJ	50% Cotton − 50% Modal	Single jersey	0.336	135
16	THC	100% Tencel	Honey comb	0.814	150
17	TSP	100% Tencel	Single pique	0.738	170
18	TSJ	100% Tencel	Single jersey	0.452	120
19	C/THC	50% Cotton − 50% Tencel	Honey comb	0.912	160
20	C/TSP	50% Cotton − 50% Tencel	Single pique	0.762	160
21	C/TSJ	50% Cotton − 50% Tencel	Single jersey	0.548	150

wales and courses per unit length (per ASTM D 3887: 1996 (RA 2008)), and loop length, among other physical and structural characteristics (ASTM D 3887). Table 1 outlines specifics of the physical and structural characteristics assessed for the fabrics.

3 Results and Discussion

3.1 Thermal Comfort Properties

3.1.1 Air Permeability

The air permeability values of each material under evaluation are shown in Fig. 2. Generally, air permeability increases across all fabrics, regardless of fibre type. When compared to fabrics made of cotton, bamboo, and tencel, modal materials exhibit improved air permeability. The fabric's ability to flow has a direct impact on its ability to provide thermal comfort. However, blending these fibres with cotton reduces air permeability. The results show that 100% modal fabrics in a single jersey structure have good air permeability. However, when modal and Tencel are blended with cotton, air permeability decreases due to the protruding fibres in the cotton structure obstructing airflow. This reduction is primarily due to the higher cotton content in the blended textiles.

3.1.2 Thermal Conductivity

Figure 3 shows that knitted fabrics have high thermal conductivity. Various combinations of the

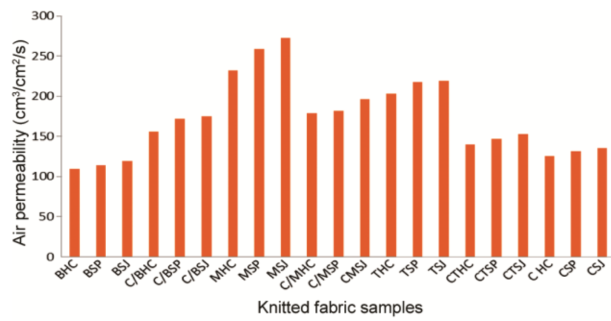


Fig. 2 — Air permeability values of knitted fabrics

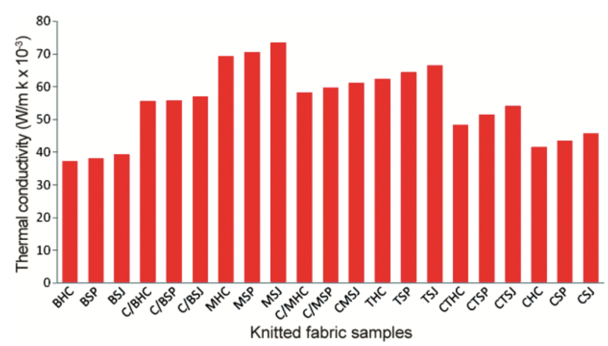


Fig. 3 — Thermal conductivity values of knitted fabrics

same fibre type have been proven by Pac *et al.*[15] to affect heat transfer. Since cellulose fibres can undergo chemical and physical treatments that alter their morphology, such as the alkaline treatment for cotton, their thermal behavior can change. As shown in

Fig. 3, the influence of fabric structure and content tends to decrease heat conductivity. Compared to cotton, bamboo, and tencel-based fabrics, modal fabrics show better thermal conduction. The fabric's capacity to move has a direct impact on how comfortable it will be to wear. These fibres when blended with cotton show decreased thermal conduction. The results indicate that fabrics made of modal and tencel have good heat conductivity, but the addition of cotton or bamboo reduces thermal conduction.

3.1.3 Thermal Resistance

Thermal resistance is a measure of a material's ability to prevent heat from passing through it. If clothes have low thermal resistance, heat energy tends to dissipate gradually, creating a cold sensation under certain climatic conditions. Fabric construction plays a significant impact on thermal resistance. Increased fabric thickness improves thermal insulation because there is less heat loss from the area it is insulating. Thermal resistance is influenced by both the thickness and thermal conductivity of a fabric. An inverse relationship is generally observed between thermal conductivity and thermal resistance[11]. As shown in Fig. 4, thermal resistance drops off in bamboo blended materials, while it is improved in the modal and tencel blended materials. This indicates that cotton's ability to resist heat is affected when it is combined with these fibres. It's also interesting to observe that the thermal conduction decreases, as GSM and fabric thickness increases. Alternating knit and tuck and knit and float stitches produces a pique structure, which inhibits the smooth, continuous passage of heat and improves thermal insulation.

3.1.4 Water Vapour Permeability

Water vapour permeability evaluates a fabric's ability to transport body moisture. If a fabric has high moisture resistance and high thermal resistance, accumulated body heat cannot dissipate effectively, leading to discomfort. Figure 5 shows the water vapour permeability values for various knitted fabrics. The lower values of mass per square metre and thickness allow water vapour to travel through the materials easily, resulting in increased water vapour permeability of modal fabrics.

The results of the water vapour permeability test are comparable to air permeability findings, where modal and tencel fabrics perform better than others due to their hydrophilic properties. Tencel and its blends are less effective compared to modal. The results in Fig. 5 indicate that one of the key influencing variables of the fabric's water vapour permeability is the type of fibre employed in it. Among fabric structures, single jersey (SJ) has the highest water vapour permeability, followed by single pique (SP) and honeycomb (HC). The fabric's structure, GSM, and thickness are the primary factors influencing this trend.

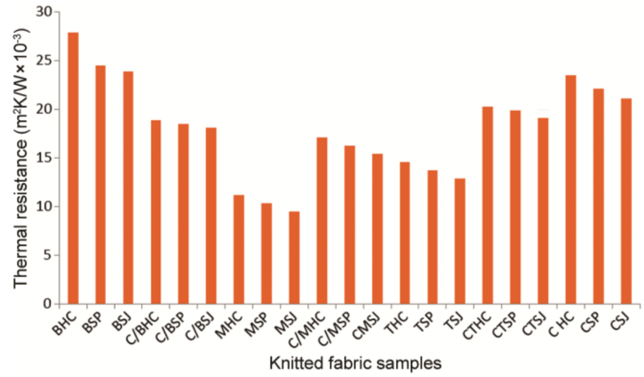


Fig. 4 — Thermal resistance values of knitted fabrics

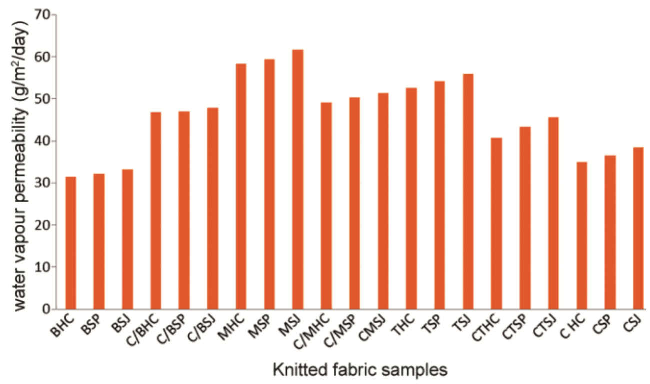


Fig. 5 — Water vapour permeability values of knitted fabrics

4 Conclusion

This study investigates how fabric structure and yarn types affect thermal comfort properties, including thermal conductivity, thermal resistance, air permeability, and water vapour permeability. The choice of yarn used in knitted fabrics significantly influences these thermal comfort characteristics. The findings of this study provide direction for the industrial production of knitted fabrics with yarn selections that are suitable for the intended usage. The results indicate that modal single jersey fabrics exhibit greater air permeability. The inverse relationship between heat conductivity and areal density is also observed. The air permeability and heat conductivity of knitted fabrics are influenced by the thickness of the fabric. In general, the fabric's openness and decreased thickness increase the fabric's water vapour permeability. Water permeability is most affected by the fabric's structure, which also affects the fabric's thickness, porosity, and areal density.

The air permeability is inversely related with fabric porosity. Similarly, the thickness and structural characteristics of the fabrics impact their thermal resistance. The thermal resistance of knitted fabrics with a single jersey structure comprised entirely of modal is lower than that of all other fabric combinations. Among all fabric combinations, 100% modal fabrics with a single jersey structure exhibit the best comfort properties, making them ideal for sportswear. On the other hand, the cotton and bamboo blended samples lack the necessary thermal comfort qualities for use in athletic textiles due to their thickness and areal density. Overall, the choice of yarn plays a crucial role in determining the thermal comfort properties of knitted fabrics.

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