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An investigation on impact of knit structure on the comfort properties of Bell Pique and its derivative structures

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This study investigates the thermal comfort and moisture management properties of weft knit fabrics, Bell Pique and its three derivative structures. The influence of knit structure on various geometric and comfort properties is evaluated, including Loop length, Wales per inch, Course per inch, Tightness factor, Bursting strength, GSM, air permeability, warmth retention rate, thermal transmittance coefficient, thermal resistance, CLO, and moisture management. To construct the fabrics, a yarn linear density of 24s N_e is used, and three different loop lengths (0.265 cm, 0.285 cm, and 0.305 cm) are tested for each knit structure. The goal of this research is to compare the performance of four knit structures and determine how they affect the comfort properties of the resulting fabrics. It was observed that original Bell Pique remains the most well-rounded fabric, offering an optimal balance of thermal properties and moisture management, making it the preferable choice for commercial use.

Keywords: Thermal comfort, Yarn linear density, Air Permeability, Thermal conductivity, Thermal resistance

1 Introduction

Comfort is a very important part of clothing, especially when it comes to how warm or cool it feels[1-3]. Things like how well clothes let air through, how they handle sweat, and how they trap heat all affect how comfortable they are to wear. The ability of clothing to manage heat and moisture plays a major role in determining comfort, making it a key consideration when selecting apparel[4-8]. Many factors can influence comfort, with thermal properties being among the most important. These include softness, flexibility and how well the fabric diffuses moisture. Recently, more researchers have focused on how fabrics affect thermal comfort, examining how factors like thermal resistance, conductivity and absorptivity are influenced by the fabric's structure, density and moisture levels. Elements such as the type of fiber, weave pattern, surface finishing, and compressibility also come into play, while air permeability and ambient temperature further impact comfort. A combination of fiber, yarn and fabric characteristics-such as spinning methods, yarn thickness, twist level and fabric thickness-work together to create the overall thermal comfort of a garment[9-13].

The primary function of performance clothing is to maintain the area next to skin at a steady temperature. It helps your body stay cool or warm, no matter what the weather is like outside or levels of physical activity. This ensures that your body's temperature control system works well in different conditions[14-17].

This present investigation aims to comparatively evaluate the comfort properties like thermal comfort and moisture management properties of weft knit fabrics, Bell Pique and its three derivative structures.

2 Materials and Methods

2.1 Fabric Structure

2.1.1 Structure No.1: Bell Pique

To create the sample, 24s Ne 100% combed cotton yarn is knitted using a bell pique structure with the knit, tuck and miss cam combination in 8 feeders with three different loop lengths: 0.265 cm, 0.285 cm, and 0.305 cm. The resulting samples are labeled as BPQ265, BPQ285, and BPQ305 for easy identification purposes.

2.1.2 Structure No.2: Bell Pique Derivative Structure 1

To create the sample, 24s Ne 100% combed cotton yarn is knitted using a bell pique structure with the

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knit, tuck and miss cam combination in 10 feeders with three different loop lengths: 0.265 cm, 0.285 cm, and 0.305 cm. The resulting samples are labeled as BPQD1265, BPQD1285, and BPQD1305 for easy identification purposes.

2.1.3 Structure No.3: Bell Pique Derivative Structure 2

To create the sample, 24s Ne 100% combed cotton yarn is knitted using a bell pique structure with the knit, tuck and miss cam combination in 8 feeders without any all knit structure with three different loop lengths: 0.265 cm, 0.285 cm, and 0.305 cm. The resulting samples are labeled as BPQD2265, BPQD2285, and BPQD2305 for easy identification purposes.

2.1.4. Structure No.4: Bell Pique Derivative Structure 3

To create the sample, 24s Ne 100% combed cotton yarn is knitted using a bell pique structure with the knit, tuck and miss cam combination in 8 feeders with placing miss cam in between two tuck cam feeders with three different loop lengths: 0.265 cm, 0.285 cm, and 0.305 cm. The resulting samples are labeled as BPQD3265, BPQD3285, and BPQD3305 for easy identification purposes.

2.1.5. Preparation of fabric samples

The Original BPQ and its three derivative structures were manufactured using 24s 100% cotton yarn, possessing the same twist level (TM=3.4). The fabrics were produced on a Mayer & Cie single jersey knitting machine (Model: D4 2.2 E12) with a 24 gauge, 26” diameter, running at 30 rpm, equipped with 84 feeders, and utilizing 1960 needles. The knitting room temperature was controlled at 30±2°C with 65% humidity. Samples were created with loop length of 0.265 cm, 0.285 cm, and 0.305 cm. The knitting was performed with consistent machine settings, and the fabrics were processed on a soft flow dyeing machine, followed by compaction using an open width compactor. Then, the sample fabrics were cut into 3-meter bits, washed in a front-loading washing machine, and conditioned in a standard atmospheric condition for 24 hours to allow for relaxation and conditioning of the samples[18-22].

2.2 Evaluation of geometric fabric properties

The geometric fabric properties, such as Wales per inch, courses per inch, stitch density, tightness factor, loop shape factor, GSM and bursting strength were assessed and their outcomes were tabulated.

Evaluation of WPI, CPI, Stitch density, tightness factor and loop shape factor

In this study, we measured Wales per inch (WPI) and courses per inch (CPI) of original BPQ and its derivatives knit structures using counting glass/pick glass, for three different loop lengths. Furthermore, we calculated the stitch density, tightness factor, and loop shape factor using the following formulas:

Stitch Density = WPI x CPI

Tightness Factor = square root of Tex / Loop length in cm

Loop Shape Factor = CPI / WPI

2.2.1 Determination of Fabric Weight (GSM)

To determine the fabric weight of BPQ and its derivative knit structures with three different loop lengths, we utilized a GSM cutter and an electronic weighing balance. Prior to measurement, the fabrics were allowed to relax under standard atmospheric conditions.

2.2.2. Determination of bursting strength

To measure the bursting strength of BPQ and its derivative knit structures with three different loop lengths, we utilized an electronic bursting strength tester. The fabrics were allowed to relax under standard atmospheric conditions prior to measurement.

2.3 Evaluation of comfort fabric properties

We also evaluated the comfort fabric properties of the BPQ and its derivative knit structures including warmth retention rate %, thermal transmittance coefficient, thermal resistance, CLO, and moisture management. Warmth retention rate %, thermal transmittance co- efficient, thermal resistance, clo were measured using a thermal conductivity tester, while moisture management properties were examined using a moisture management tester. All measurements were carried out in a controlled standard atmospheric environment[23].

2.3.1 Air Permeability

Air permeability is the amount of air, measured in cubic centimeter per second, which passes through 1 cm² of fabric under a pressure of 1cm of water. This property is influenced by the material and structural characteristics of the fabric, including the size and distribution of pores in the yarn and fabric. And other factors like weave, type of yarn and yarn density play a vital role in determining air permeability. This parameter is commonly used to assess the breathability of the fabric, indicating its ability to allow air circulation. The air permeability of the fabric was tested using an air permeability machine and followed IS: 11056-1984 test method under standard conditions like 20 ±2°C and relative humidity of 65 ±2%. Each sample was measured ten times and the mean along with standard deviation were calculated[24].

2.3.2 Thermal conductivity Test

A thermal conductivity tester was used to assess the warmth retention %, thermal transmittance co-efficient, thermal resistance and CLO values and followed JISL 1018 test standard. Each sample was measured five times and the mean along with standard deviation were calculated. All tested were conducted under standard atmospheric conditions to ensure accuracy[21-24].

2.3.3. Moisture Management Test

The moisture management properties of the fabrics were examined using the AATCC195- 2009 test on an SDL Atlas Moisture Management Tester M-290. This test measured the fabric's water absorption, flow rates, and drying time. The speed at which water spread across the upper and lower surfaces was recorded, and the data were used to calculate the percentage of liquid transport through the fabric. The overall moisture management capacity (OMMC) was determined based on three factors: the absorption rate on the bottom surface (ARB), one-way liquid transport capacity (R), and the maximum spreading speed on the bottom surface (SSB). These measurements reflected the fabric's water resistance, repellency, and absorption behavior, influenced by its structure and the wicking properties of its fibers and yarns. Each sample was measured ten times and the mean along with standard deviation were calculated. All tests were conducted under controlled atmospheric conditions[25-26].

3. Results and Discussion

3.1. Geometric properties

3.1.1. Impact on WPI, CPI, Stitch Density, Tightness factor and loop shape factor

From the Table 1, the results indicate that both BPQ and its derivative knit structures exhibit similar behavior, with an increase in loop length resulting in a reduction in WPI, CPI, stitch density and tightness factor, except loop shape factor[27]. The loop shape factor of BPQD1 & BPQD2 increases as the increase in loop length, whereas the loop shape factor of BPQ and BPQD3 decrease as the increase in loop length. Furthermore, the BPQ was found to be approximately 8%, 33% and 40% denser than its derivative knit structures BPQD1, BPQD2 and BPQD3 respectively.

3.1.2. Impact on Fabric weight (GSM)

The GSM (grams per square meter) of knit fabrics is affected by several factors such as knit pattern, yarn linear density, and the fabric's dimensional characteristics. From Figure 1, Fabric density has a significant influence on the fabric weight[26]. Increasing the loop length of bell pique and its derivative structures leads to a decrease in fabric GSM. Notably, BPQ is slightly denser than its derivative structures, resulting in a slightly higher fabric GSM. These results indicate that fabric GSM can be regulated by choosing the appropriate knit structure.

3.1.3. Impact on Bursting strength

The bursting strength of knit fabrics can be influenced by various factors, including the knit structure, yarn linear density and stitch length. From

Table 1 — Geometric properties results of sample knitted fabrics.

Fabric Quality	Loop Length in cm	WPI	CPI	Stitch Density	Tightness Factor	Loop Shape Factor
BPQ265	0.265	32	85	2720	18.7	2.66
BPQ285	0.285	31	79	2449	17.4	2.55
BPQ305	0.305	31	71	2201	16.3	2.29
BPQD1265	0.265	33	74	2442	18.7	2.24
BPQD1285	0.285	32	72	2304	17.4	2.25
BPQD1305	0.305	30	68	2040	16.3	2.27
BPQD2265	0.265	30	68	2040	18.7	2.27
BPQD2285	0.285	28	64	1792	17.4	2.29
BPQD2305	0.305	26	60	1560	16.3	2.31
BPQD3265	0.265	30	70	2100	18.7	2.33
BPQD3285	0.285	29	60	1740	17.4	2.07
BPQD3305	0.305	27	53	1431	16.3	1.96

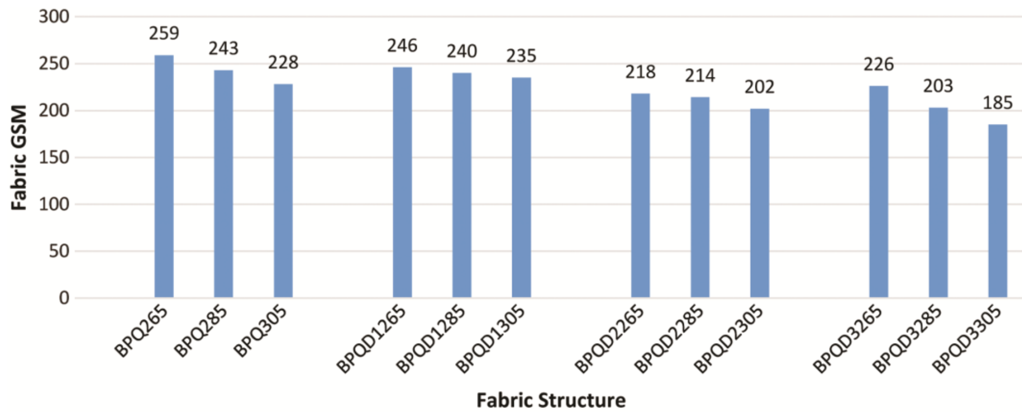

Fig. 1 — GSM results of sample knitted fabrics

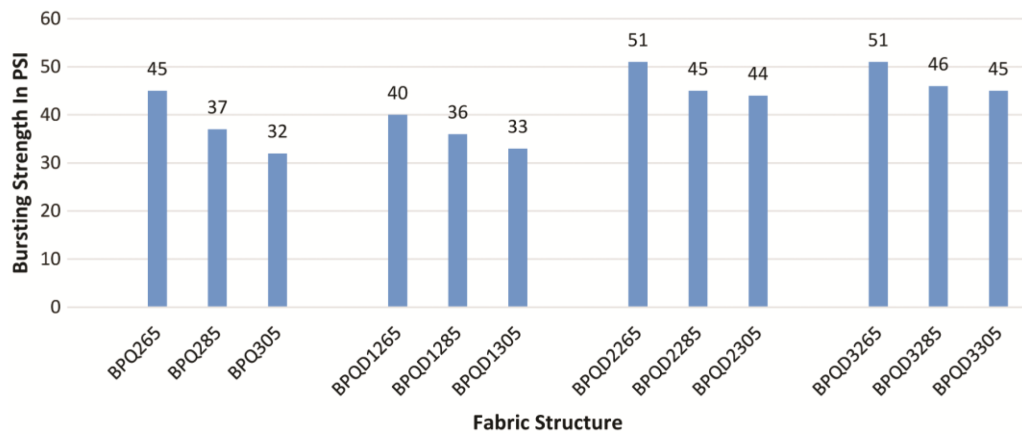

Fig. 2 — Bursting strength test results of sample knitted fabrics

Figure 2, all the four structures exhibit similar behavior, with the increase in stitch length, the bursting strength decreases due to the higher number of loops per square inch present in fabrics with shorter stitch length. Moreover, the bursting strength of BPQ is higher than BPQD1 and lower than BPQD2 & BPQD3. However, the BPQ meets the commercial requirement for sufficient bursting strength[27].

3.2. Comfort properties

3.2.1. Effect on Air permeability

Air permeability is crucial for the thermal regulation and moisture control of clothing, especially for summer sportswear. It is commonly used to assess the "breathability" of fabrics. For a functional breathable material, it's essential that body – produced water vapour can readily evaporate into the environment and prevent the penetration of liquid water from outside into the garment. This balance helps in maintaining dry feeling during wear. Greater air permeability enhances the overall performance. As depicted in Figure 3, as the stitch length increases, the air permeability increases across all four-knit structure. The results indicate that the original BPQ structure exhibits a higher air permeability when compared to derivative structure

BPQD2 and BPQD3. This suggests that BPQ's inherent fabric design offers greater airflow, contributing to its breathability. However, BPQD1 demonstrates superior warmth retention compared to the original BPQ structure due to its variations in fabric density and porosity[21].

3.2.2. Impact on Warmth Retention Rate (%)

The warmth retention rate refers to the percentage of heat a material or garment retains when subjected to specific temperatures of environment conditions. It reflects show effectively the fabric can trap and maintain body heat to keep the wearer warm. This rate is determined by measuring the heat retained by the fabric and comparing it to the initial amount of heat generated by the body. A higher warmth retention rate indicates better insulation properties of the material or garment. As depicted in Figure 4, as

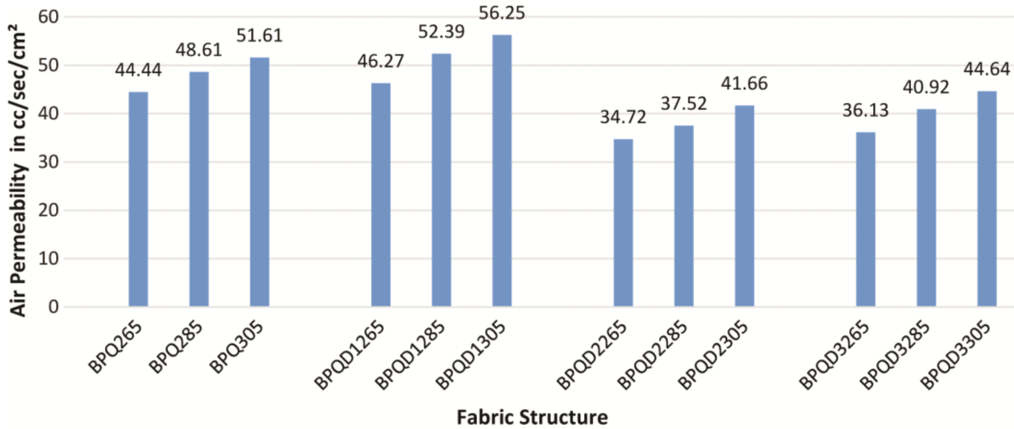

Fig. 3 — Air permeability test results of sample knitted fabrics

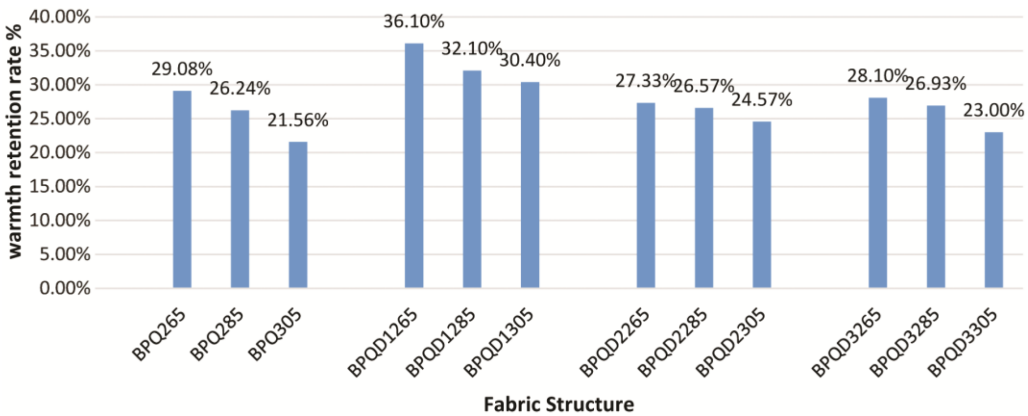

Fig. 4 — Warmth retention rate % test results of sample knitted fabrics

the stitch length increases, the warmth retention rate % decreases across all four-knit structure. The results indicate that the original BPQ structure exhibits a higher warmth retention rate compared to derivative structure BPQD2 and BPQD3. This suggests that BPQ's inherent fabric design offers better insulation and heat retention qualities. However, BPQD1 demonstrates superior warmth retention compared to the original BPQ structure due to difference in fabric density, porosity and surface texture[27].

3.2.3. Impact on Thermal Transmittance COEF

The thermal transmittance co-efficient, commonly known as the U-value, measures the speed at which heat passes through a material and is represented in watts per square meter per degree Celsius, it shows how much heat passes through a unit area of the material per unit time when there is one-degree Celsius difference between indoor and outdoor temperatures. The U- Value reflect show well a material resists the heat loss or gain. Lower U-value corresponds to better insulation, as they indicate that less heat is transferred through the material. The U-Value is influenced by factors such as material's thermal conductivity, thickness and any air gaps or the presence of insulation layers[26].

From Figure 5, all four structures exhibit similar behavior, as the loop length increase resulting in increase in thermal transmittance co-efficient. The results indicate that original BPQ exhibits better thermal transmittance co-efficient when compared to BPQD2 and BPQD3. However, BPQD1 shows slightly better performance than original BPQ.

3.2.4. Impact on Thermal resistance

Thermal resistance ($m^2.K/W$) measure show well a material or assembly resists the transfer of heat. It is the reciprocal of the thermal transmittance co-efficient (U-value) and is expressed in square meters per degree Celsius per watt ($m^2.K/W$). This thermal resistance reflects the amount of resistance a material of assemble provides for a given thickness. A greater thermal resistance value signifies the material is better at preventing heat transfer. Thermal resistance is

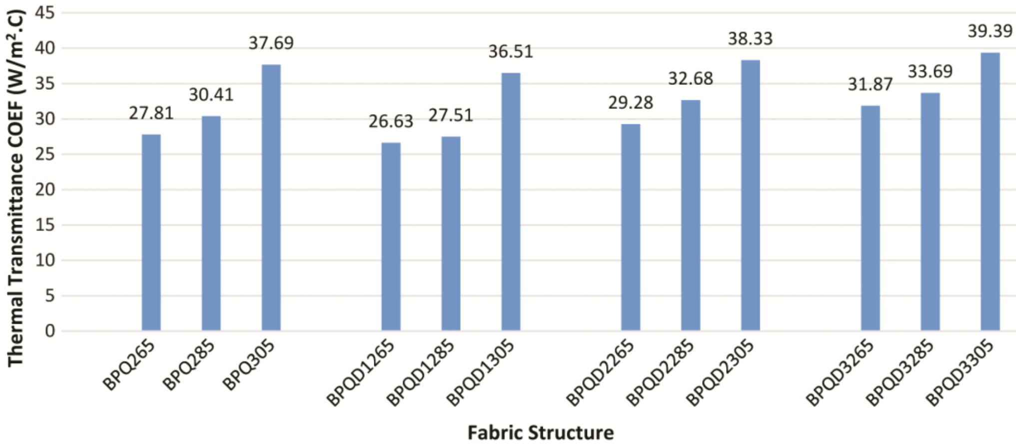

Fig. 5 — Thermal transmittance co-efficient test results of sample knitted fabrics

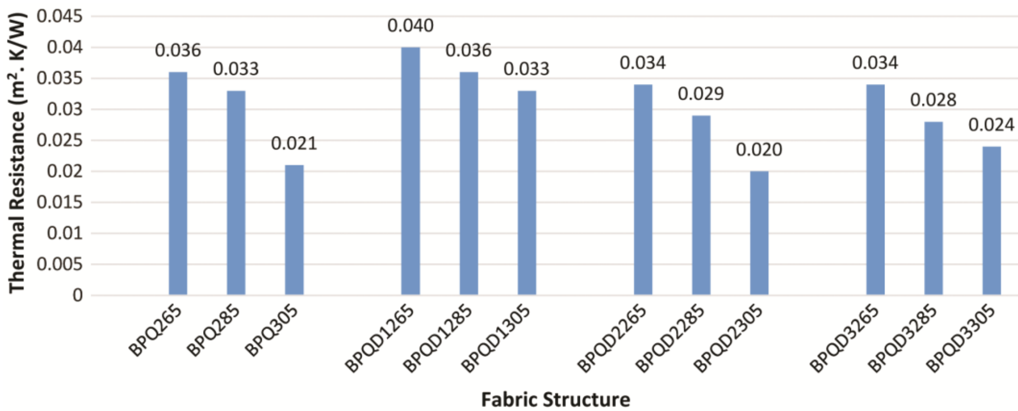

Fig. 6 — Thermal resistance test results of sample knitted fabrics

influenced by both the material's thickness and its thermal conductivity, which determines how quickly heat travels through the material[25].

As illustrated in Figure 6, the results indicate that original BPQ structure exhibits better thermal resistance, when compared to BPQD2 and BPQD3. However, BPQD1 shows slightly better performance than original BPQ.

3.2.5. Impact on CLO

The CLO value is a unit used in the textile and clothing industry to quantify the thermal insulation or heat-retaining capacity of garments. It represents the level of insulation a piece of clothing provides under specific environmental conditions, such as a set temperature and humidity[22-24].

A CLO value of 1 corresponds to the insulation required to keep a person at thermal comfort in a neutral environment, typically around 21°C (70°F) with 50% humidity. For instance, a garment with a CLO value of 2 offers double the insulation of one with a CLO value of 1 in similar conditions.

As depicted in Figure 7, the results indicate that BPQ exhibits better CLO value, when compared to BPQD2 and BPQD3. However, BPQD1 shows slightly better performance that original BPQ.

3.2.6. Impact on Moisture Management

Moisture management refers to a textile material or garment's capability to regulate the movement and distribution of moisture, such as sweat and water vapour, away from the skin to ensure comfort and enhance performance. Efficient moisture management requires moving moisture away from the skin's surface to the outer layer of the fabric, allowing it to evaporate into the surrounding air. As detailed in Figure 8, the moisture management of BPQ and BPQD1 decreases as the loop length increases, whereas the BPQD2 and BPQD3 increases as the loop length increase and Table 2 explains the accumulative one-way transport index, mean OMMC overall moisture management capacity and moisture management results of BPQ, BPQD1, BPQD2 and BPQD3 at all three different loop lengths[24-27].

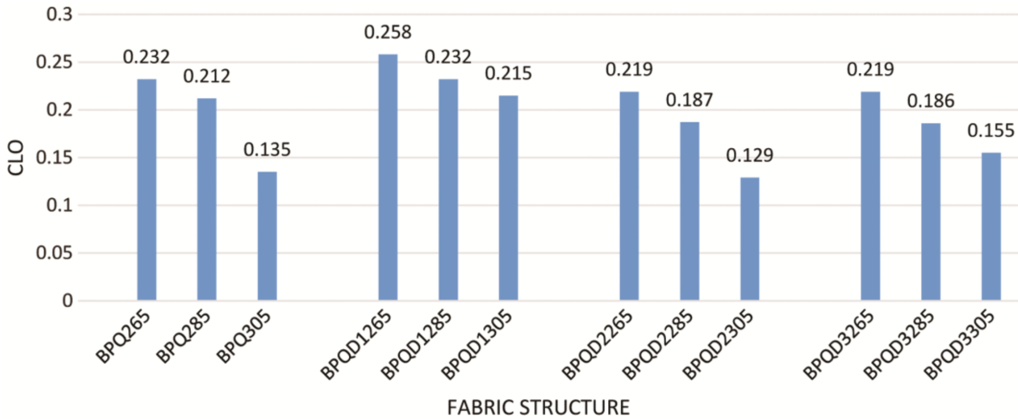

Fig. 7 — CLO test results of sample knitted fabrics

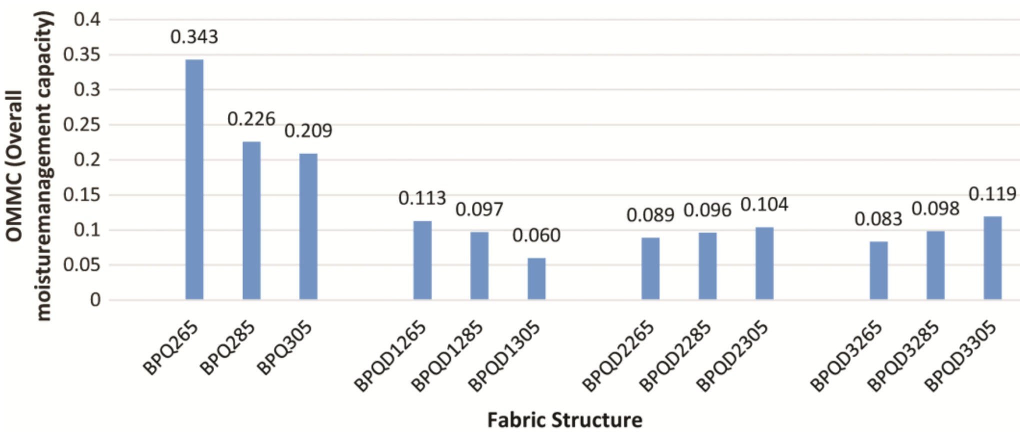

Fig. 8 — Moisture management results of sample knitted fabrics

Table 2 — Moisture management performance of sample knitted fabrics

Fabric Structure	Accumulative one-way transport index	Mean OMMC (OverallMoisture management capacity)	Moisture management results
BPQ265	119.99	0.343	Moisture management fabric
BPQ285	31.71	0.226	Fabric absorbing/Slow drying fabric.
BPQ305	45.38	0.209	Fabric absorbing/Slow drying fabric
BPQD1265	3.3	0.1129	Slow absorbing/Slow drying fabric
BPQD1285	2.65	0.097	Slow absorbing/Slow drying fabric
BPQD1305	2.52	0.0602	Slow absorbing/Slow drying fabric
BPQD2265	1.95	0.0887	Slow absorbing/Slow drying fabric
BPQD2285	2.58	0.0959	Slow absorbing/Slow drying fabric
BPQD2305	2.57	0.1041	Slow absorbing/Slow drying fabric
BPQD3265	2.28	0.0833	Slow absorbing/Slow drying fabric
BPQD3285	1.29	0.0981	Slow absorbing/Slow drying fabric
BPQD3305	2.48	0.1194	Slow absorbing/Slow drying fabric

4 Conclusion

The results of this study provide an accurate and deep understanding on thermal and moisture management performance of BPQ and its derivative structures BPQD1, BPQD2 and BPQD3. The original BPQ exhibits superior performance in several key thermal properties, including air permeability, warmth retention rate, thermal transmittance co-efficient, thermal resistance and CLO, when compared to BPQD2 and BPQD3. This indicates that BPQ's design is optimized for heat retention and thermal efficiency. BPQD1 demonstrates slightly better thermal performance that the original BPQ. Although it offers marginally improved warmth retention and thermal resistance, but it falls short in critical areas such as bursting strength, which makes it unsuitable for meeting commercial durability requirements. Additionally, BPQ significantly outperforms all three derivative structures in terms of moisture management, a key factor for comfort in wear.

In conclusion, even though BPQD1 shows potential alternative to original BPQ in terms of thermal performance, its poor bursting strength limits its practical applications. On the other hand, Original BPQ remains the most well-rounded fabric in offering an optimal balance of thermal properties and moisture management, making it preferable choice for commercial use.

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