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Moisture and Thermal Comfort Properties of Heat Resistance Protective Work Wear Using Cotton and Cotton/Polyester Blended Weft Knitted Fabrics

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ABSTRACT

This research paper investigates the impact of physiological properties and end-use conditions of heat-resistant protective work wear on the wear comfort response. In this paper, material features and test methods are screened to obtain weft knitted fabric characteristics that explain wear comfort effectively. physiological and moisture properties including liquid moisture transfer properties are assessed for Single jersey 100% cotton, 50/50 cotton/polyester, Rib structures 100% cotton, 50/50 cotton/polyester and Interlock structures with 100% cotton and 50/50 cotton/polyester weft knitted structures with a constant loop length and machine parameters. Six heat resistant work wear materials with different fiber content, yarn property, knitted type and functional finishes. Based on the thermo physical values, small differences among the test garments are predicted. Measured moisture properties, attained from fabric mechanical, surface and liquid moisture management properties, provide more distinctive comparisons. The remaining moisture is calculated from the vaporized and total driven water to forecast the feeling of wetness after sweating. Results from surface roughness, contact area and wet cling analysis show that softer yarns, finer fibers and single jersey, rib and interlock produce measurably smoother fabrics with small contact. And the effects of hydrophilic fiber blending and wicking finishes on the moisture management properties are also examined. These results are discussed in relation to the wear comfort response in variable conditions of physical activity and environment.

Keywords: *Moisture management, thermal comfort, knitted structures, weft kitted structures*

Introduction

Knitting is the processes of forming fabric by interlooping yarn in a series of connected loops by means of needles. Knit fabrics provide outstanding comfort qualities due to their inherent softness and flexibility and have long been preferred in many types of clothing. In general, comfort is defined as "the absence of displeasure or dis comfort", or "a neutral state compared to the more active state of pleasure (Chidambaram, Govindan, & Venkatraman, 2012).In addition to this thermal comfort is defined as the state of mind, which expresses satisfaction with the thermal environment and comfort is imparted by the extensible looped structure knits also provide lightweight warmth, wrinkle resistance and ease of care (Van Hoof, Mazej, & Hensen, 2010).

The human body strives to keep its core temperature at 37oC and the metabolic heat generation for a person engaged in physical activity is in the range of 800-1300W. The extra body heat is produced causing the nervous system to respond by sweating. Sweat glands pump perspiration through pores, body heat is transported to the sweat, causing it to vaporize and cool the body (Suganthi & Senthil Kumar, 2017). The structural properties (i.e., fabric density, thickness, porosity, weight...) and material type of fabrics are crucial in the determination of the moisture management properties of fabrics. The ultimate objective of managing moisture in fabrics is to ensure moisture is transported to the outer surface in the shortest possible time. The knitting parameters (such as structure and stitch density) predominantly influence the knitted fabric physical characteristics (i.e., thickness, weight, and porosity), which thus influence the fabric comfort properties (Teyeme, Malengier, Tesfaye, Vasile, & Van Langenhove, 2020).

Some researchers conclude that knitted fabrics used for Abaya and investigates their thermal comfort properties. The results showed that knit structure, fibre composition and other fabric properties affect the thermal comfort performance. The polyester/elastane (96/4) single jersey knit fabric showed better air permeability, stretch & recovery properties, lower thermal & water vapour resistance compared to nylon filament fabric, polyester/cotton (65/35) single jersey, wool single jersey fabric and 50/50 wool/nylon fabric. It is evident that the knitted polyester/elastane fabric construction appears to be more suitable for Abaya fabric (Tashkandi, Wang, Kanesalingam, & Jadhav, 2013).

On the other hand some results demonstrated that some properties, such as, thermal properties, diffusion ability, air and water vapor permeability are influenced by both raw material type and knitted structure parameters (Onofrei, Rocha, & Catarino, 2011). And also for wearer comfort, this sweat would be transported away from the skin surface, in the form of liquid or vapor, so that the fabric touching the skin feels dry. The transport of both moisture vapor and liquid away from the body is called moisture management (Onofrei et al., 2011).

Moisture management is one of the key performance criteria in today's apparel industry which decides the comfort level of any fabric. The consumer's demand for comfort performance of the garment is on high rise and inevitably apparel manufacturers have been compelled to shift their attention towards the high-performance of moisture management technology and market. And some of the review incorporates the necessity of moisture management in textile apparel aims of development of moisture management fabrics, technical approach towards the moisture management, preferred attributes of moisture management fabrics, the role of moisture management, numerous concepts of moisture managing textiles, developments in moisture management techniques and functional fields of application of moisture management technique (Basuk, Choudhari, Maiti, & Adivarekar, 2018).

The purpose of this study was to compare the thermo physiological comfort properties of 100% cotton and 50/50 cotton/polyester single jersey weft knitted structures, 100% cotton and 50/50 cotton/polyester rib weft kitted structures and 100% cotton and 50/50 cotton/polyester interlock weft knitted structures. This is determined to be advantageous in different wear protective fabrics by using these fabric types. In addition to the difference in research findings of the moisture management and thermal comfort properties of the cotton polyester weft knitted fabric, we proposed a set of tests for companies to provide the quality control and choice of fabrics for the same purpose, to support a well-informed platform in the design and development of future wearing protective functional knitted fabrics.

2. Materials and Methods

2.1. Materials

100% cotton and 50/50 cotton polyester single jersey weft knitted structures, 100% cotton and 50/50 cotton polyester rib weft kitted structures and 100% cotton and 50/50 cotton polyester interlock weft knitted structures. Work wear weft knitted fabrics were specially produced for this research. Single jersey, rib and interlock weft knitted fabrics were manufactured on a weft knitting machine with the following machine settings: circular knitting, gauge 18, cylinder diameter 24″, speed 35 rpm, feeders 76 and number of needles 1728; the ambient knitting room conditions of relative humidity (RH) 65±2% and a temperature (temp.) 30±2°C. All the samples were produced with constant machine parameters and loop lengths (2.8mm) which allowed the same knit structures. And also weft Knit fabrics were produced under constant machine settings and ambient room conditions; and the produced samples were conditioned at standard atmosphere conditions (RH 65±2% and temp. 25±2°C) for at least 24 h for preceding to testing. A comparison of fabric structural properties of cotton and polyester weft knitted fabrics. All test fabrics were given three launderings according to the AATCC method before testing to remove any possible dirt and oils from the processing lines (Yoo & Barker, 2005).

2.1.1. Production of weft Knitted Fabrics

The knitted fabrics for this research are produced from 100% cotton and, 50/50 cotton polyester single jersey weft knitted structures, 100% cotton and 50/50 cotton polyester rib weft kitted structures and 100% cotton and 50/50 cotton polyester interlock weft knitted structures.

2.2. Test Methods

Weft knit fabric physical properties such as thickness (mm), areal density (g/m2), and volume Porosity, air permeability (cm3/s/cm2, bulk density (g/m3), moisture management properties and thermal comfort properties (thermal conductivity, thermal resistance, air permeability and water-vapor permeability) were measured and statistically evaluated.

2.3. Physical Properties of Knitted fabrics

Weft knit fabric wales per inch (WPI) and courses per inch (CPI) were measured according to the ASTM standard. Fabric thickness (mm) was determined according to ASTM standard using Shirley thickness tester. Fabric areal density (g/m2 or GSM) was calculated according to ASTM using electronic balance. Weft knit fabric loop length (mm) is constant for all samples that is 2.8mm. Volume porosity (%) of the fabric was calculated as explained by (Elnashar, 2017).

$$VP = \frac{1000\,\pi[2d_v\, d_H\, \gamma\, 4T\, D_Y]10/2}{d_{NK}\, T\, \gamma \sqrt{[1-0.01\, C_{VH}]100}} + \frac{L_{LY}\, R_W}{N_{YR}}\, X\, \frac{1}{IFC}$$

Where symbols description for equation:
VP = volume porosity,
TNK = thickness of knitted fabrics.
T: Yarn count in Tax system.
C: Crimp for knitted fabrics (vertical-horizontal).
Dy: Density of yarns/cm.
γ: *Scientific
dV: Vertical Cross section for loop yarn.
(dH): Horizontal Cross section for loop yarn.
LLY: Length of loop yarn "weft" extended between tow intersections in perfect repeat of knitted construction.
RW: Width of repeat of loop "wale".
NYR: Number of Crouse repeats for loop "weft".
*Scientific (fiber) density for cotton (1.54)- viscose (1.46)- polyester (1.38) – Acrylic fiber density is 1.17 (g/cm3).

IFC: Integration factor construction [IFC (in regular structure) gouge) = 1].

IFC = Σ (α X W) / n (15).

Where: α: Balance factor of knitting construction. W: width of stripe (density). n: number of wale width stripes (density).

Where: K= C n √ N. For direct system. C= is the constant for material, (0.04126 for Tex.). n = number of course threads per inch. N = yarn count

Averages of five readings were taken for each physical property measured in Table 1 and 2.

Table 1. Description of Test Materials

Weft knit fabrics	Description	Weight (g/m^2)	Thickness (mm)	Bulk density (kg/m^3)	Air permeability ($cm^3/s/cm^2$)	Optical porosity (%)
single jersey	100%cotton	150.6	0.89	165	144	2.12
	50/50 cotton polyester	157.5	0.98	158	150	1.98
Rib structure	100% cotton	155.7	0.84	175	142	2.29
	50/50 cotton polyester	162.8	0.99	154	135	2.25
Interlock structure	100% cotton	170.6	0.92	190	98	1.45
	50/50 cotton polyester	185.8	1.04	179	38	0.98

2.3.1. Thickness measurement of knitted fabrics

The thickness tester is used to fix the thickness of weft knitted fabrics. Digital display range of thickness 0.01~25mm (optional 0.001~25mm), Measuring accuracy 0.01mm (optional 0.001mm), Lowering speed of pressing-foot 1.72 mm/s. Area of pressing foot 2500 mm2 and Load weight 100cN Pressing duration 30s The mean value of all the readings of thickness was determined to the nearest value and the calculated result is the average thickness of the sample under test. The nonwovens thickness was determined in according to the digital thickness tester with ASTM D-1777 standard method (Astm, 1996).

Figure 2.1. Digital thickness tester machine

2.3.2. Air permeability measurement of knitted fabrics

The amount of airflow passing through perpendicularly to a known area of fabric is adjusted to obtain a suggested air pressure differential between the two fabric surfaces and it's normally articulated in terms of cm3/s/cm2 calculated at working conditions. From the amount of airflow, the air resistance of the nonwovens is resolute in accordance with the ISO9237:1995Test Method. The measurements was carried out by using 20 cm2 circular fabric with 100 Pa pressure difference for 1 second and the results was expressed in cm3/s/cm2 by taken the average of four different measurement. The test was performed according to ISO 9237:1995 test method.

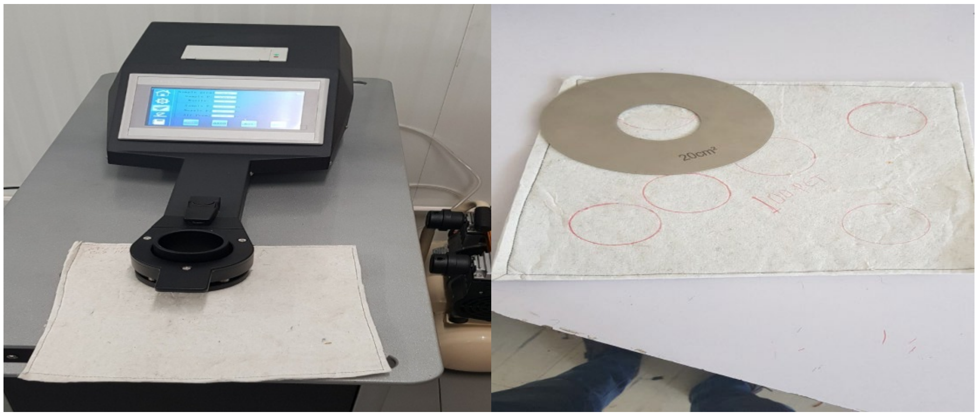

Figure 2.2. GT-C27B Automatic air permeability tester

2.3.4. Thermal Comfort Properties of knitted fabrics

The Alambeta instrument was used in the measurement of thermal conductivity and thermal resistance values according to ISO standard .Heat flux sensors detect the amount of heat flow from the hot plate to the cold plate through the fabric. This measurement procedure is explained by (Vadicherla & Saravanan, 2017). And also Oğlakcioğlu and Marmarali (2007) they studied about thermal properties of cotton and polyester based single jersey of 1×1, rib and interlock structures were statistically investigated. The thermal properties of samples were measured using Alambeta and Permetest devices. The results indicate that each knitted structure tends to yield rather different thermal comfort properties. Interlock and 1×1 rib fabrics have a remarkably high thermal conductivity and thermal resistance value. On the other hand, single jersey fabrics have higher relative water vapour permeability values than 1×1 rib and interlock fabrics, and give a warmer feeling with lower thermal absorptivity values (Oğlakcioğlu & Marmarali, 2007).

2.3. Moisture management properties of knitted structures

They discussed about moisture management properties of fabrics were the top surface refers to the surface in contact with the skin. The bottom surface refers to the surface exposed to the atmosphere in the MMT test device. Regulation of body temperature when the human body core temperature exceeds 37oC sweat is produced(Hussain, Nazir, & Masood, 2015; Onofrei et al., 2011).They explained that moisture management can be defined as the controlled movement of water vapour and liquid moisture from the surface of the skin to the atmosphere through protective heat resistance worn by a wearer. They reviews that some fundamental principles and basic mechanisms involved in liquid moisture management, along with some recent developments in fiber, yarn, knitting and topical finishing for enhancing the moisture management properties of knitted fabrics(Hussain et al., 2015).

3. Results and Discussion

Statistical Data Analysis: Evaluation of the test results was made using SAS 9.0 for Windows statistical software. The study for each thermal property (air permeability, thermal resistance, thermal conductivity and water vapour permeability) and moisture management properties was examined by one-way analysis of variance (ANOVA) with a confidence level of 95%. In this study, the statistical significance of fabric characteristics were explained (Table 1 and 2). Statistical analysis also indicates that the results are significant for air permeability, thermal resistance and thermal conductivity and water vapour permeability of the fabrics.

Table 2. Thermal and vapor transfer properties and thermal comfort limits measured at moderate conditions (21°C, 65% R.H.)

Weft knit fabrics	Description	Thermal insulation (clo)	Thermal resistance (m^2K/W)	Permeability index(i_m)	Vapor resistance (m^2Pa/W)	Thermal comfort limit (W/m^2)	Maximum heat loss (W/m^2)
single jersey	100%cotton	0.451	0.060	0.310	11.21	260	545
	50/50 cotton polyester	0.455	0.061	0.334	10.17	266	579
Rib structure	100% cotton	0.446	0.058	0.402	10.32	269	578
	50/50 cotton polyester	0.457	0.061	0.443	9.57	269	605
Interlock structure	100% cotton	0.464	0.062	0.322	13.25	243	480
	50/50 cotton polyester	0.422	1.055	0.174	23.98	234	369

3.1. Thermal comfort properties

The measured and calculated properties related to heat and vapor transfer under steady-state conditions are given in Table 2. These data demonstrated that the weft knitted fabric thermal insulation (clo) was comparable for all test weft knitted fabrics. In general, we find that dry thermal insulation is correlated with weft knitted fabric thickness. Considering the structural properties of the test knitted fabrics, the result looks reasonable since all the test fabrics were organized within a certain range in their thickness and weight. These data also show that evaporative heat transfer, (im), was controlled by fabric porosity. Interlock 50/50 weft kitted fabric, with the lowest optical porosity, indicates the smallest evaporative heat transfer. Successively, due to the lower involvement of evaporative heat loss, the total heat loss was less through 100% interlock cotton weft knitted fabric and especially through Interlock 50/50 weft kitted fabric, due to the higher bulk density and lower permeability of these materials relative to the other test fabrics (See Table 1and Table 2).

3.1.2. Knitted fabric thickness

Fabric thickness is one of the important knitted fabric parameters influencing the insulation properties, handle and material consumption. The yarn thickness has a direct impact on the knitted fabric thickness. It equals the yarn diameter if a round yarn cross-section is presumed.

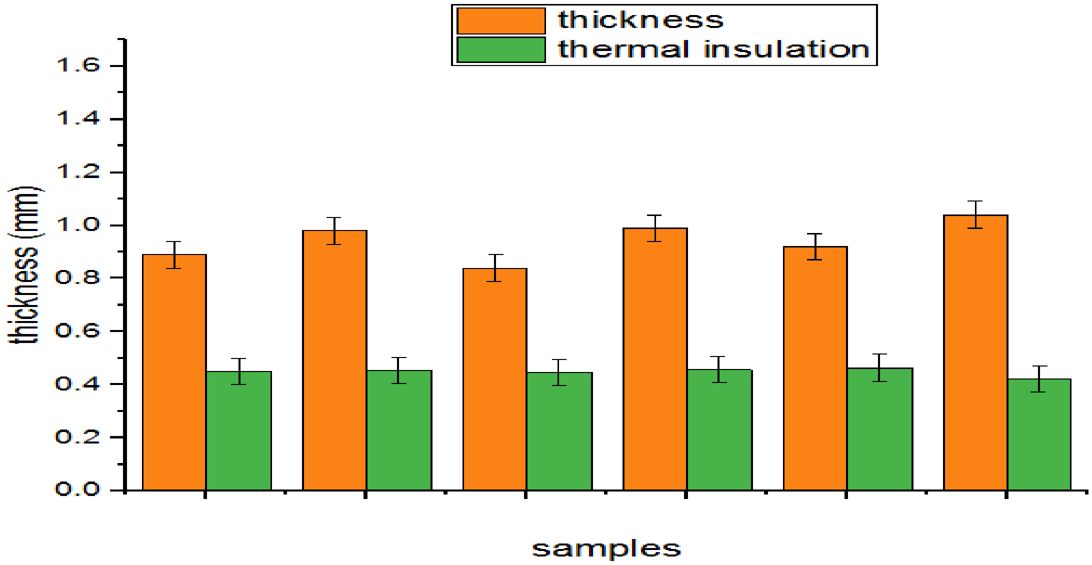

Figure 3.1. Thickness of weft knitted samples

From figure 3.1 it is observed that 50/50 cotton polyester weft knitted interlock structures have higher thickness than the other. The thickness of single jersey, 1×1rib, interlock knitted fabrics made from 100% cotton and polyester (50/50%) blended yarns is different. The thickness of knitted fabrics made from 100%cotton are lower than the same fabrics made from cotton/polyester blended yarns because the fabrics made from cotton/polyester yarns have greater width wise shrinkage which leads to higher thickness of the fabrics. The same study performed by (Sitotaw, 2020)

3.1.3. Kitted fabric areal density

From figure 2.2 it is observed that single jersey, rib and interlock knit fabric structures which detected relationships among the GSM (Gram per square meter),Stitch length and GSM (gram per square meter) are the two major parameters for making a knit fabric. The relationship between stitch length (S.L) and GSM is inversely proportional if the other parameter remain constant. Similarly, increase in linear density results in thicker, heavier and less porous fabric with higher thermal conductivity, lesser air permeability and thermal resistance and high relative water vapor permeability at medium linear densities explained by (Slater, 1977).

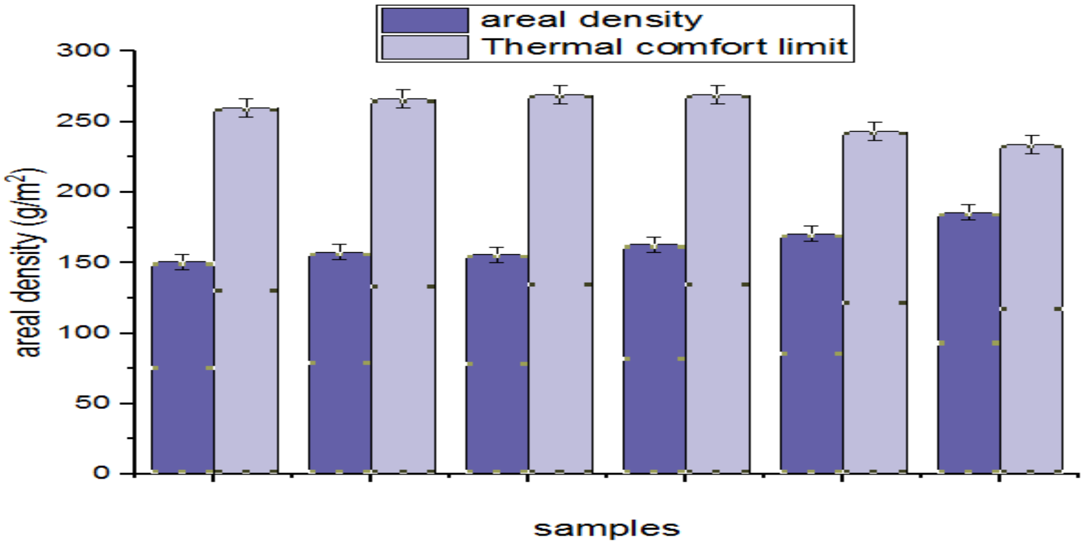

Figure 3.2. Areal density of knitted fabrics

3.1.4. Bulk density of knitted fabrics

From the figure 3.3 the results show that absorbent capacity of liquid moisture was determined primarily by weft knitted fabric structure. Consequently fabrics having the greatest bulk density rib100% cotton and 50/50 cotton/polyester, interlock 100% cotton and 50/50 cotton/polyester have been exhibited the highest water absorption capacities. Absorbency rate and wetting time, on the other hand, were mainly influenced by the wettability of the fabric surface.

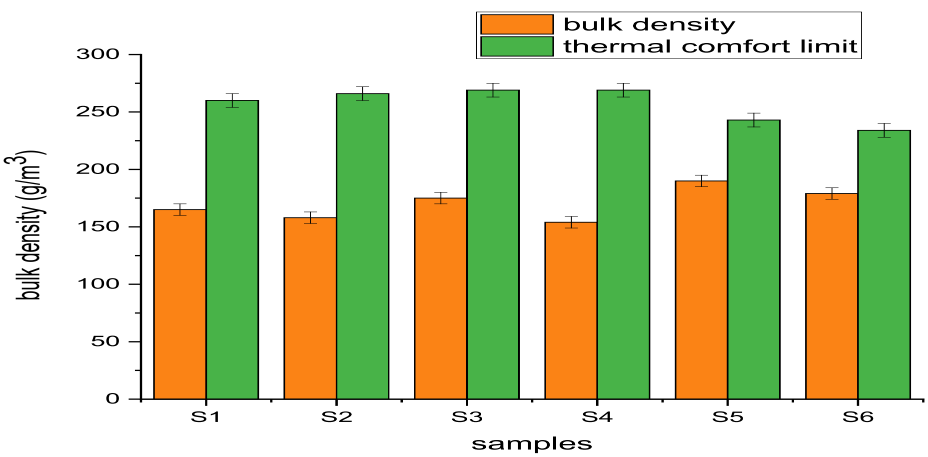

Figure 3.3. Bulk density of knitted fabrics with thermal comfort limit

3.1.5. Air permeability of knitted fabrics

From figure 3.4 it is observed that single jersey 50/50 cotton polyester weft knitted fabrics have higher air permeability than the other fabrics. The air permeability of a fabric can affect its comfort behaviours in several ways. In the first case, a material that is permeable to air is, in general, likely to be permeable to water in either the vapour or the liquid phase. Thus, the moisture-vapour permeability and the liquid-moisture transmission are normally related to air permeability.

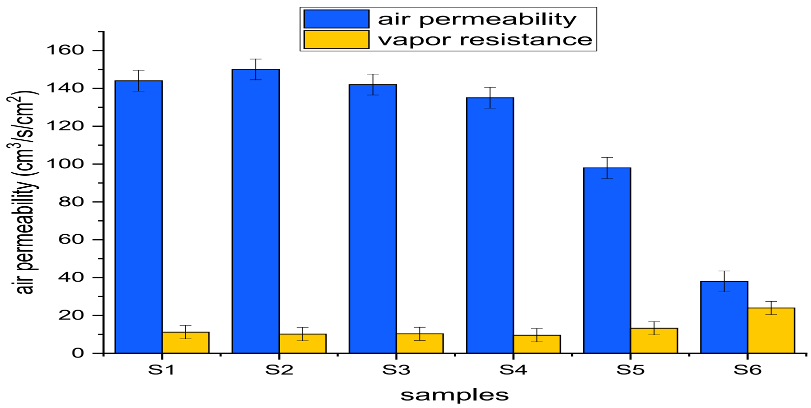

Figure 3.4. Air permeability of knitted fabrics with vapor resistance

3.1.6. Porosity of knitted fabrics

Heat and liquid sweat generation during sports activities must be transported out and dissipated to the atmosphere. A key property influencing such behaviours is porosity. The yarn diameter, knitting structure, course, wale density, yarn linear density, pore size and pore volume are the main factors affecting the porosity of knitted fabrics. And also it was determined that the loop length of a knitted jersey has more influence on porosity than the stitch density and the thickness (Bhattacharya & Ajmeri, 2014).

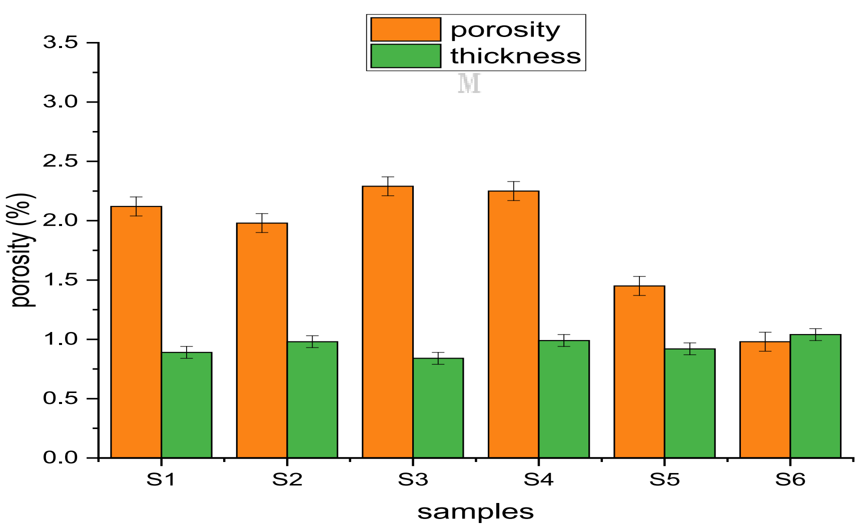

Figure 3.5. Porosity of knitted fabrics with thickness

From figure 3.5 we have observed that rib 100%otton and 50/50cotton polyester weft knitted fabrics have higher volume of porosity than the others. Porosity is one of the key properties influencing thermo-physiological comfort of the wearer.

3.2. Thermal insulation and thermal resistance of knitted fabrics

Thermal insulation and thermal resistance in able 2 the results of thermal insulation and thermal resistance Rct (m2K/W) of knitted fabrics are given. Thermal resistance of interlock 50/50 cotton polyester greater than that of single jersey and rib weft knitted fabrics. Cotton/polyester knitted fabrics have the highest thermal resistance. Single jersey and rib knitted fabric has the smallest. This distribution of values for thermal resistance in cotton and polyester knitted fabrics is the result of a heavier knitted fabric, more mass per unit area have higher thermal conductivity.

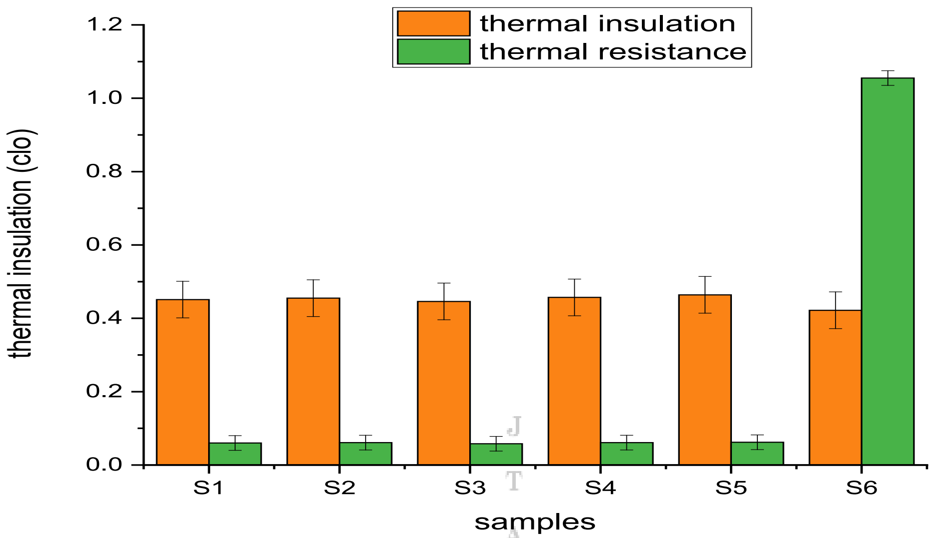

Figure 3.6. Thermal insulation with thermal resistance of knitted fabrics

From figure 3.6 it is observed that single jersey100% cotton, single jersey 50/50cotton polyester, rib100% cotton, rib50/50cotton polyester and interlock 100% cotton have similar thermal insulation value and inter lock 50/50 cotton polyester has lower thermal insulation value. And interlock 50/50 cotton/polyester weft knitted fabrics have higher thermal resistance value as compared to the others (Oğlakcioğlu & Marmarali, 2007). They reported that thermal resistance is a measure of the body's ability to prevent heat from flowing through it. Under a certain condition of climate. If the thermal resistance of clothing is small, the heat energy will gradually reduce with a sense of coolness. From the figure it observed that interlock 50/50 cotton/polyester weft knitted fabric have higher thermal resistance than the others. However, the other 100% cotton single jersey, 50/50cotton polyester single jersey, 100% cotton rib, 50/50cotton polyester rib and 100% cotton interlock have almost similar thermal resistance properties as observed from the above figure. The same results are obtained from (Oğlakcioğlu & Marmarali, 2007).As the fabric thickness increases the thermal resistance the increases. Both the cotton and polyester fabric samples gave the lowest thermal resistance values for the single jersey and rib structure and the greatest values were obtained for the interlock weft knitted structure.

3.3. Liquid Water Transport

When a wearer begins to perspire, the liquid moisture management properties of the material are more important than vapor moisture management properties. Table.3indicates the absorption capacity, rate of absorption and water retention measured using the AATCC standard modified to permit evaporation. Also shown are the wetting time, measured using a drop test and the moisture regain. Moisture absorption from the vapor phase (% regain) was determined by the hydrophilicity of the fiber component in the fabric.

Table 3. Moisture management properties

samples	Regain (%)	Wetting time(min)	Absorbent capacity V (cm^3)	Absorbent Rate$Q1$ (cm^3/min
S.100% cotton	5.91	4.41	1.045	0.39
S.50/50COTTON POLYESTER	5.93	2.21	1.064	0.45
R.100% cotton	7.52	18.52	1.025	0.27
R.50/50COTTON POLYESTER	7.63	5.93	1.064	0.38
I.100% cotton	5.54	12.54	1.144	0.39
I.50/50COTTON POLYESTER	7.71	1.95	1.412	0.72

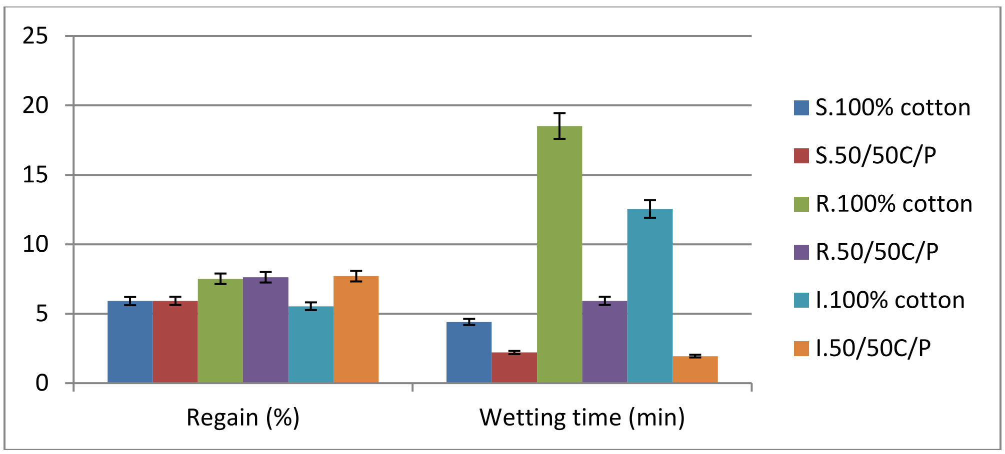

Figure 3.7. Moisture regain and wetting time of knitted fabrics

3.3.1. Moisture regain and wetting time of knitted fabrics

From the figure 3.7 we observed that rib100% cotton and rib 50/50cotton polyester wet knitted fabrics have higher regain (%) than others. And also rib 100% cotton and interlock100% cotton weft knitted fabric have higher wetting time than the others.

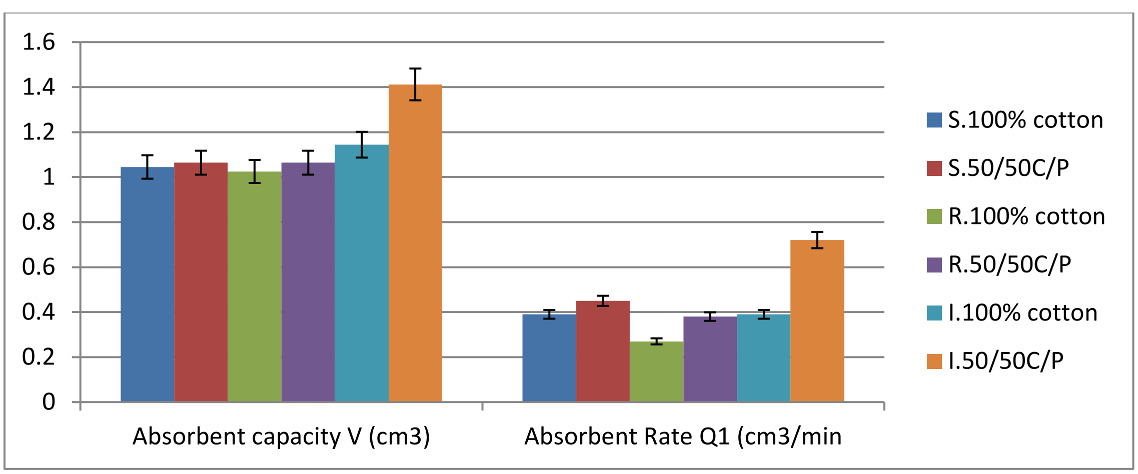

Figure 3.8. Absorbency capacity and absorbency rate of knitted fabrics

3.3.2. Absorbency capacity and absorbency rate of knitted fabrics

From the figure 3.8 it observed that interlock 100% cotton and 50/50 cotton polyester tended to hold a greater amount of water after evaporation.in terms of water absorption capacity and absorbency rate interlock 100% cotton and 50/50 cotton polyester have higher than that of the other weft knitted structures.

4. Conclusion

From the comfort studies we have investigated the impact of fabric constructional variables on the thermal comfort and moisture management properties of heat resistant protective work wear cotton and cotton/polyester weft knitted fabrics. Thermal comfort and moisture management properties including liquid moisture transfer properties of weft knitted fabrics were evaluated for six heat-resistant work wear materials which are 100% cotton single jersey, 50/50 cotton polyester single jersey, 100% cotton rib, 50/50 cotton polyester rib, 100% cotton interlock and 50/50 cotton polyester interlock weft knitted fabrics with different fiber content, yarn property and functional finishes. Heat and vapor transfer properties are typically connected with fabric breathability and it was found that none of the test materials would be thermally uncomfortable under normal environmental conditions even with heavy workloads. The liquid moisture management properties provide more distinctive comparisons. From the results it is estimated that there would be no significant differences in thermal comfort among the heat resistant protective work wear fabrics tested in this study. In terms of thermal comfort interlock 100% cotton and interlock 50/50 COTTON POLYESTER weft knitted fabrics have some advantages. Sweat management properties can be expected by using moisture uptake and drying properties. 50/50COTTON POLYESTER rib and 50/50 COTTON POLYESTER interlock weft knitted fabrics that incorporate a water wicking treatment can be estimated to exhibit higher rates of sweat uptake and protective heat resistance work wear than the other weft knitted fabric structures.

Authors' Contributions

Dr. Sakthivel S. and Meseret Bogale and Senthil Kumar researched data, undertook data processing, contributed to data analysis, interpretation, and preparation of the manuscript. A contributed to the direction of the study, supervised data acquisition, reviewed and revised the manuscript.

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