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Liquid transfer properties and drying behavior of plated knitted fabrics with varying fibre types

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The present study aims at investigating the effect of face yarn linear density and back layer fibre type on the liquid transfer properties and drying behavior of single jersey plated knitted fabrics. Fabrics knitted with coarser yarns exhibit high water absorbency, slow drying capability (characterized by lower water evaporation percentage) and appear to be unsuitable for high activity levels. Polypropylene/cotton fabric is found to be the preferred choice at high activity levels owing to lower water absorption, higher trans planar wicking and higher water evaporation percentage. Plated fabrics with nylon in the next to skin layer show high water absorption, poor trans planar wicking and slow drying capability. Nylon/cotton fabrics are, therefore, found to be ineffective in providing dry microclimate next to skin and may not be suitable at high activity levels.

Keywords: Absorbency, Comfort, Drying, Knitted fabrics, Polyester, Polypropylene, Wicking

1 Introduction

Comfort is one of the most crucial aspects of clothing as it strongly affects the buying behavior of consumers. Clothing particularly intended for next to skin applications, active wear and sportswear must be able to balance the body's thermal function and create microclimate next to skin during changing activity levels and environmental conditions[1]. In essence, vigorous physical activity and hot, humid conditions are generally accompanied by the onset of sensible perspiration as a means to dissipate any excess amount of heat generated by the body[2, 3]. The inability of clothing to readily release the perspiration outside may increase the effective garment mass, sometimes causing garment clinging to the skin, resulting in cold, clammy feeling and potential discomfort to wearer[4]. Liquid transfer properties and drying ability of fabrics are therefore crucial for perceived comfort performance of textiles during intense physical activities.

Evaporation of sweat is the dominant mechanism by which fabric and clothing dries during wear. The liquid moisture transfer and quick drying behavior of textiles depend mainly on capillary capability and moisture absorbency of the fibres along with free surface energy as well as size and shape of fibres, fibre fineness, fibre surface smoothness, yarn structure, twist, fabric thickness and porosity[5-8]. Water absorption depends on total amount of water that can be absorbed regardless of time and speed of water uptake[9]. According to Crow and Osczevski[10] the amount of water freely picked up by fabric is determined by fabric thickness; the more water fabric holds initially, the longer it takes to dry. Liquid transfer through textiles involves two sequential processes, namely wetting and wicking (Fig. 1). Wetting is the initial process involved in fluid spreading. Fibre-liquid interface replaces fibre-air interface during the wetting process[8]. The forces in equilibrium in a solid-liquid boundary are described by the following the Young-Dupre equation:

$$Y_{SV} - Y_{SL} = \mathrm{Y}_{\mathrm{LV}}\ Cos\,\theta \qquad \ldots(1)$$

where γ is the tension at interface between combinations of solid (S), liquid (L) and vapor (V); and θ, the contact angle between liquid drop and surface of solid to be wetted.

Wicking is an important means of providing comfort under conditions of profuse sweating, occurring during exercise in hot environment[11]. The ability to sustain capillary flow is defined as wickability[12-14]. Capillary pressure (P) which causes liquid transport inside capillaries is a function of surface tension of liquid γ, contact angle θ, and radius

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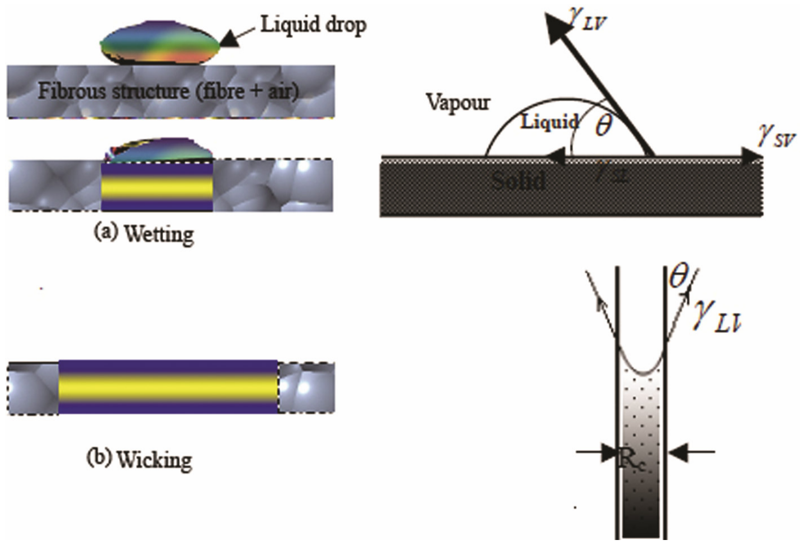

Fig. 1 – Wetting and wicking phenomenon in textile structures[10]

of pore r_i its magnitude is generally given by following Laplace equation:

$$P = \frac{2\gamma \mathrm{Cos}\,\theta}{r_i} \quad \dots (2)$$

Plated knit structures are double-layered single jersey fabrics designed with careful selection of distinct fibre and yarn combinations in the technical face and back side[15]. One layer of plated knitted fabric is next to skin and serves as a wicking layer to transport sweat in vapor and liquid form to the outer layer. The layer not in direct contact with skin is the outer layer of plated knitted fabric which serves as a sink by absorption of transferred sweat and evaporation to environment[1]. According to different water absorbability of used fibre materials in the face and back layers, double layered knitted fabric can be divided into four types, viz (i) hydrophobic yarn in both face (outer) and back (inner) layers, (ii) hydrophilic yarn in back and hydrophobic yarn in the face layer, (iii) hydrophilic yarn in both face and back layers, and (iv) hydrophobic yarn in back and hydrophilic yarn in the face layer as illustrated in Figs 2(a)-(d).

Correct selection of fibres in the distinct face and back layers of plated fabrics appears to be crucial for effective liquid transfer and drying of fabrics for providing dry microclimate next to wearer's skin. A variety of natural and synthetic fibres are finding application in double-layered fabrics, active wear, innerwear and sportswear owing to unique characteristics and features of each fibre. While

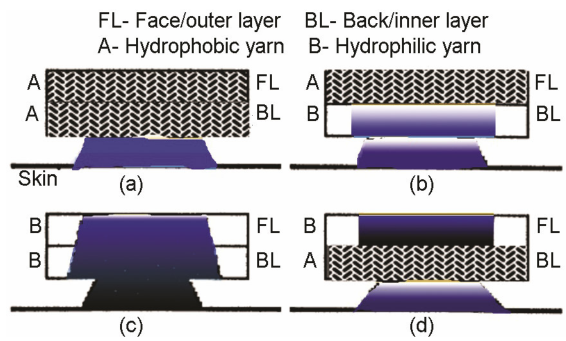

Fig.2 – Double layer fabrics with different water absorbability in face and back layers[23]

natural fibres being hydrophilic are considered suitable for low activity levels, synthetic fibres are hydrophobic and generally preferred choice as base layer for high activity levels. Hydrophilic fibres have a high surface energy so they pick up moisture more readily than hydrophobic fibres which have low surface energy and repel moisture[16]. Natural fibres owing to high moisture regain are slow drying and may add to dampness, clinginess and garment weight when wet. Synthetic fibres have an additional advantage of keeping garment lighter than natural fibres when wet, are quick drying and possess good shape retention property, thus making them suitable for next to skin applications[17, 18]. Several researches have been devoted to understand and establish the influence of fibre types, fibre shapes, yarn count, yarn blends, yarn twist, fabric bulk properties and structures on the comfort properties of knitted fabrics. Reported literature suggests that several fibre, yarn and fabric variables strongly affect the liquid transfer properties and drying behavior of fabrics and determine their suitability for particular end use.

Fangueiro *et al.*[19] studied the wicking and drying ability of knitted fabrics produced from blends of wool- coolmax and wool- fine cool. It was reported that fabrics with coolmax fibres could transport perspiration quickly from the skin to environment and show the best capillarity performance. Mehrtens & Mcalister[11] reported low wicking ability for nylon fabrics as compared to cotton and orlon fabrics. Ozturk *et al.*[3] studied the influence of fibre type and yarn count on wicking properties of cotton- acrylic yarns and fabrics and suggested that the wicking ability of yarns and fabrics increases with the increase in acrylic content in the blends and with the use of coarse yarns.

Das *et al.*[13] studied the interactive effect of blend proportion, yarn count and twist level on in-plane and vertical wicking of polyester-viscose blended fabrics. They observed that wicking height and in-plane wicking of the fabrics are reduced with the increase in yarn fineness and twist.

Bedek *et al.*[20] evaluated the moisture management properties of knitted underwear fabrics and observed that a cotton underwear fabric has the longest drying time which is correlated to the highest moisture regains and lowest air permeability of the fabrics.

Fabrics knitted from cotton yarn and synthetic thread combination show greater area of liquid spot on inner and outer surfaces and would dry more rapidly compared to fabrics knitted from man-made bamboo yarn and synthetic thread combination[1].

Long[21] investigated the water transfer properties of two-layer weft knitted fabrics and observed that the water absorption of the fibre materials in the two layers influences the liquid water transfer from the inner to outer layer.

The published literature reveals extensive and detailed studies on comfort characteristics of different knitted structures; however, there are very limited studies devoted to the thermal, moisture vapour, liquid moisture transfer properties air permeability and drying behavior of plated knitted structures. In the view of foregoing, comfort properties of plated knits particularly, thermal properties, air permeability and moisture vapour transfer properties of plated knits with varying hydrophobic fibres in the back (next to skin) layer and varying yarn linear density in the face layers were studied and reported in an earlier study[22]. However, the liquid transfer properties of the developed samples were not included in the above mentioned study. Systematic studies on the influence of distinct combinations of hydrophilic and hydrophobic fibres on liquid transfer and drying behavior of plated knitted structures needs to be further explored. Hence, the present study has been aimed at investigating the influence of face yarn linear density and back layer fibre type on liquid transfer properties and drying behavior of plated knitted fabrics.

2 Materials and Methods

2.1 Materials

Cotton ring-spun yarns of varying yarn linear densities, and polyester, polypropylene and nylon continuous filament yarns were used for the preparation of nine plated knit structures. The details of yarn and fabric characteristics of developed samples have already been reported earlier[22]. All nine samples were prepared on hand operated flat knitting machine. The details of the machine used for the knit sample preparation has been provided in the earlier study[22].

2.2 Methods

2.2.1 Physical Characterization

Fabric aerial density was determined according to ASTM D-1059. The thickness of fabric samples was measured on Alambeta (Sensora, Czech Republic). The fabric density was determined as the ratio of fabric aerial density and fabric thickness. Tightness factor and porosity of the plated fabrics were determined using the equations [Eqs (1) and (2)] as reported in previous study[22].

2.2.2 Comfort Characteristics

(i) Water Absorbency

Gravemetric absorbency tester (GATS) was used to measure the liquid absorption in the direction perpendicular to fabric plane. It is capable of continuous measurement of the amount of liquid, absorbed by fabric as a function of time that is unaffected by gravity. Figure 3 shows the components of gravimetric absorbency tester. Output of GATS is the total amount of fluid loss determined from change in weight of fluid reservoir as function of time. The parameter absorbent capacity (C) is assessed as per the following equation:

$$C = \frac{V}{W} \qquad \ldots (3)$$

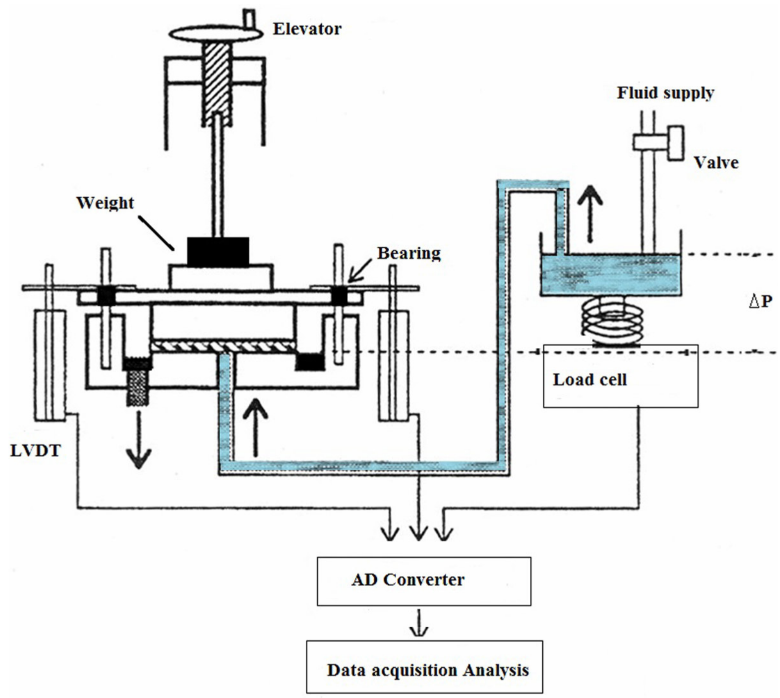

Fig.3 – Components of gravimetric absorbency tester (GATS)

where C is the absorbent capacity (cc fluid/g dry fabric); V, the maximum amount of fluid absorbed in specimen (cc); and W, the mass of die cut dry fabric (g).

(ii) Drying Behavior

Water evaporation (WE) percentage indicates the ability of textiles to evaporate the absorbed liquid moisture and hence the drying capability of textiles. For the calculation of water evaporation, 200mm^2 specimen was placed on the balance, and the fabric weight was recorded as w_f (g). The weight of water added to fabric equal to 30% of the fabric weight before adding water was designated as w_o (g). The change of water weight w_i (g) at regular intervals was recorded continuously. The water evaporation percentage which expresses the change of water weight remained in the specimen over time was calculated using the following equation:

$$\text{WE }\% = \frac{w_o - w_i}{w_o - w_f} \times 100 \qquad \ldots (4)$$

3 Results and Discussion

3.1 Water Absorbency

Water holding ability is closely related to fibre type. The higher the moisture regain and the looser the thread construction, better is the water holding ability[9]. Figures 4 (a)- (c) show that the water absorbency of the fabrics increases as the face yarn linear density increases for all fabrics (PC1-PC3, NC1-NC3 and PPC1-PPC3). The fabric thickness increases as the cotton yarn linear density increases; degree of contact at yarn interstice being greater for thick yarns than in thin ones, thick fabrics would hold more water in their yarn interstices than in thin ones. Decrease in compactness of yarn structure and increase in bulkiness of yarn, thus increasing availability of air spaces in yarn structure with increase in yarn linear density, may also lead to increase in water absorbency for coarser fabrics.

N/C fabric shows the highest water absorption, irrespective of face yarn linear density and PP/C fabrics absorbs the least mass of water. The observed trend can be explained by the mechanism of water absorption by textile structures. Absorptive capacity gives combined value of absorption of water by fibre molecules as well as moisture fill up in inter-fibre and inter-yarn pores of the material. Amount of water taken up by pores depends on porosity of material, however the absorption of water molecule by fibre depends on the presence of hydrophilic groups in the material. If porosity increases, water entrapment by pores will also increase[13]. Since in the present study, PET/C, PP/C and N/C fabrics are knitted with same tightness factor, the amount of water taken up by pores would nearly be the same. However, owing to the difference in hydrophillicity of the three fibres used, water uptake by fibres will vary, depending on the nature of fibre. This indicates the difference in water absorbency for three types of fabrics. Nylon has amide linkage (N-H group) for every 6 carbon atoms in chain giving regain of 16% if each amide group holds one water molecule. This suggests that the amount of water absorbed by the fibre molecules increases with the increase in water absorbing sites. Polypropylene fibre is a long chain synthetic polymer composed of at least 85% (by weight) propylene with additional – CH side group which is a non polar group and under standard conditions the moisture regain of polypropylene is very close to 0, even at saturation level the regain ranges from 0% to 1% (refs 2,18). Hence, it can be inferred from the discussion that PP/C fabrics show the lowest water absorption. Results are in accordance with the findings of Bivainyte and Mikucioniene[1] who reported that fabrics knitted from polypropylene and cotton yarn combinations show worst ability to absorb water.

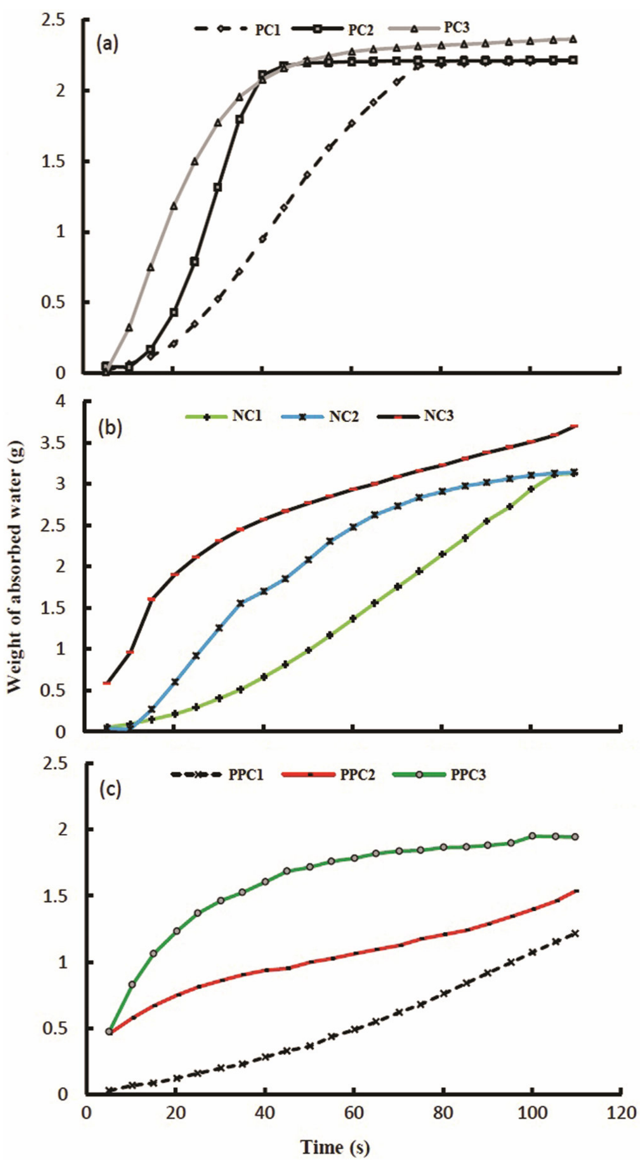

Fig.4 – Effect of face yarn linear density on water absorbency of (a) polyester-cotton (b) nylon-cotton and (c) polypropylene-cotton plated fabrics

3.2 Trans Planar Wicking

Trans planar wicking is the transmission of water through thickness of fabric i.e. perpendicular to plane of fabric, also termed as demand wettability[23]. Figure 5 shows the effect of face yarn linear density and fibre type on trans planar wicking. It is observed that with the increase in face yarn linear density from 29.5tex to 39.4tex, trans planar wicking initially increases, but with further increase in face yarn linear density (59.1tex) the trans planar wicking decreases, irrespective of the fibre type. The initial increase in wicking with increase in face yarn linear density may be attributed to the presence of more capillaries as well as the continuity of capillaries formed by fibres in coarse yarns. The observed trend may also be a result of high thickness values of fabrics knitted from coarser yarns, as fabric thickness can provide more space to accommodate water, which, in turn, can lead to more water transferred. However, with further increase in face yarn linear density the wicking decreases due to low capillary pressure as suggested

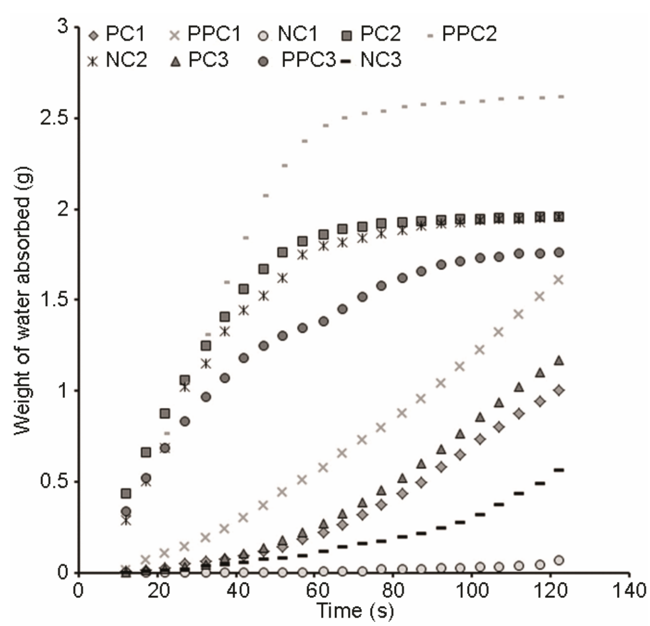

Fig. 5 –Effect of face yarn linear density and fibre type on trans planar wicking

Table 1 – Physical properties and liquid transfer properties of plated fabrics

Sample code	Thickness mm	Weight g/m^2	Porosity %	TF tex$^{1/2}$/cm^2	WE %				
					5 s	10s	15s	20s	25s
PC1	1.21	405	76.9	14.0	15.4	24.5	33.3	41.4	49.8
PC2	1.30	448	76.2	15.0	8.8	15.9	25.1	33.4	40.1
PC3	1.40	470	76.8	17.0	4.9	10.5	14.5	18.7	23.7
PPC1	1.20	350	76.1	14.0	20.3	24.8	37.3	42.3	52.8
PPC2	1.30	370	76.6	15.0	13.2	23.4	31.1	42.8	52.3
PPC3	1.41	400	76.7	17.0	6.7	12.9	18.9	24.5	25.7
NC1	1.20	380	76.2	14.0	7.2	12.5	17.8	24.4	25.8
NC2	1.31	410	76.5	15.0	5.7	10.2	14.7	21.6	23.9
NC3	1.40	440	76.4	17.0	4.4	8.8	13.3	20.0	22.2

TF– Tightness factor and WE% – Water evaporation percentage.

by Kissa[23], who stated that there is an optimum capillary size that will cause fastest entry of water into the yarn pores. Larger than optimum pores will also slow down entry due to low capillary pressure. Hence, both too small and too large pores are detrimental to quick wicking. Comparison of plated fabrics with varying fibre types shows that PP/C fabrics show the highest value of trans planar wicking and N/C fabrics are observed to have the lowest value of trans planar wicking. Wicking process is kinetically quite different when capillary penetration is accompanied by liquid diffusion into fibres. Volume of liquid flowing in capillary spaces decreases by liquid sorption within fibres and swelling of fibres reduces the inter fibre spaces available for capillary penetration[23]. Nylon fibre inhibits the liquid movement through capillaries due to blockage of inter-fibre capillaries caused by water absorption by fibres, however, polypropylene fibre provides sufficient drag for liquid movement along the capillaries owing to its hydrophobicity and accordingly PP/C fabrics exhibit higher values of trans planar wicking.

3.3 Water Evaporation Percentage

Water evaporation percentage indicates the fabric ability to evaporate the liquid from outer surface to the environment and hence determines the fabric drying capacity. Evaporation-drying ability is closely related to fibre type and moisture releasing ability as well as fabric thickness, construction and fabric weight[9].

Table 1 and Figs 6 (a)-(c) show the water evaporation percentage of plated fabrics with varying face yarn linear densities. Irrespective of the fibre type, water evaporation percentage decreases as the face yarn linear density increases, indicating that coarser fabrics would take longer to dry compared to

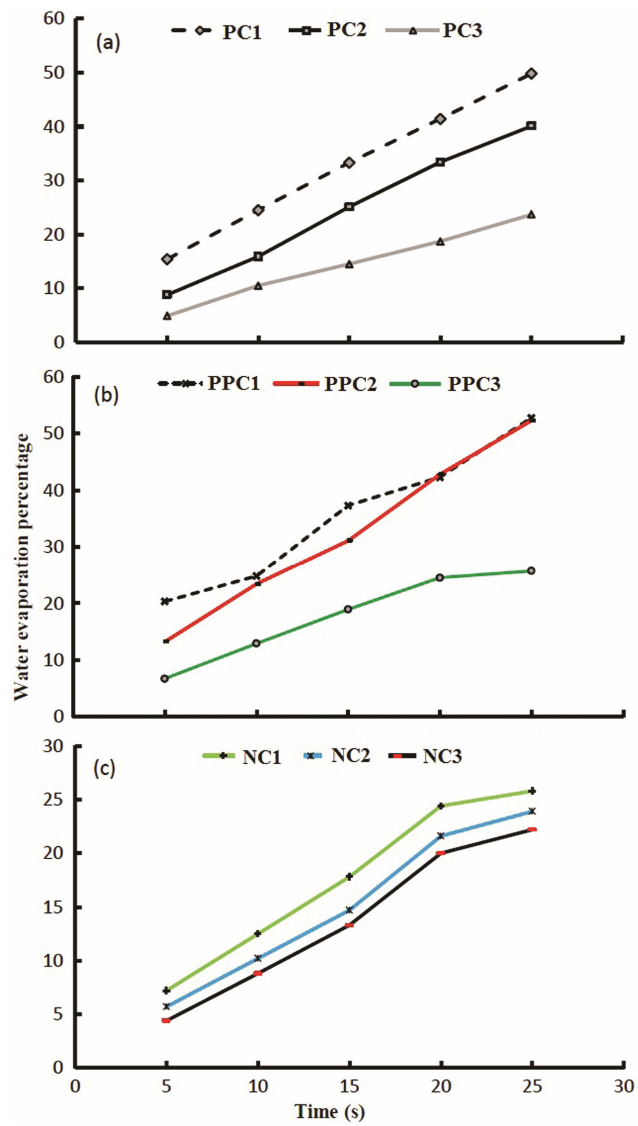

Fig. 6 – Effect of face yarn linear density on water evaporation percentage of (a) polyester-cotton (b) polypropylene-cotton and (c) nylon-cotton plated fabrics

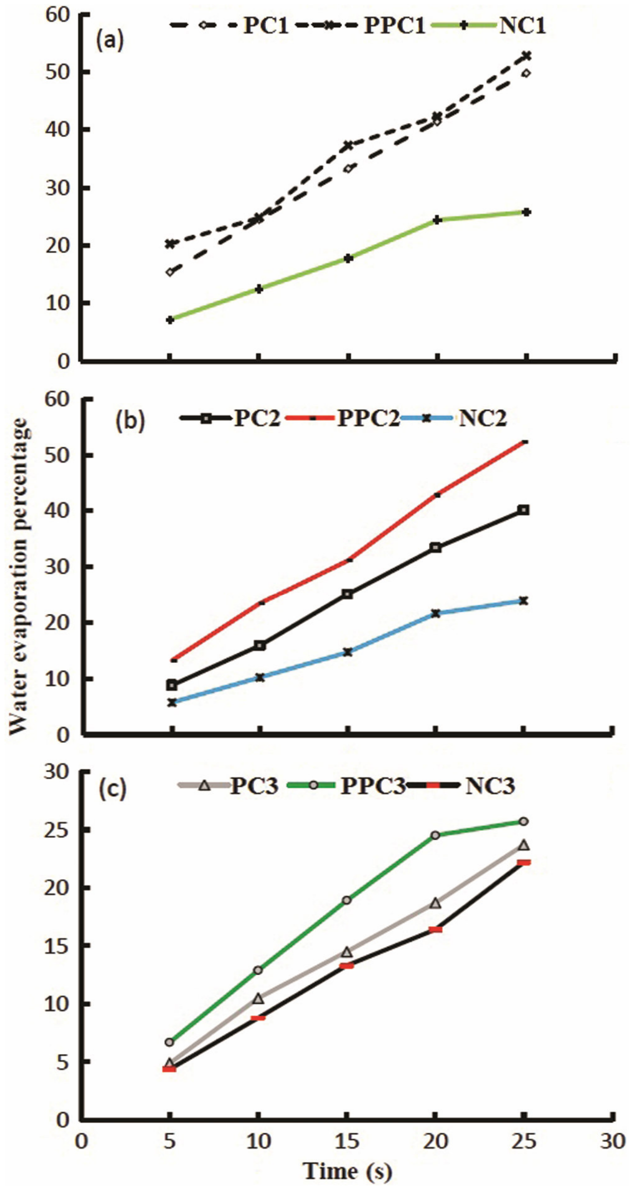

Fig.7 – Effect of fibre type on water evaporation percentage of plated fabrics

fine fabrics. This may be due to higher thickness and larger amount of water absorbed by coarser fabrics. It has been reported that linear relationship exists between time to dry and initial mass of water in specimen. The time fabric takes to dry is directly related to amount of water which is in the fabric initially, the more water it holds initially, the longer it takes to dry[10]. Figure 7 shows the effect of fibre type on water evaporation percentage of plated knitted fabrics. PP/C fabric would be the quick drying fabric owing to highest water evaporation percentage, irrespective of the face yarn linear density. However, N/C fabric would be the slowest drying fabric owing to the lowest water evaporation percentage. Nylon with high moisture regain due to higher number of hydroxyl groups available for bonding with water can absorb larger mass of water and hence N/C fabric would take longer to dry due to higher mass of initially absorbed water; polypropylene however being hydrophobic fibre with moisture regain close to 0 does not absorb water and due to low mass of absorbed water PP/C fabrics exhibit high values of water evaporation percentage.

4 Conclusion

Water absorbency increases and water evaporation percentage decreases with increase in face yarn linear density. Trans planar wicking initially increases with the increase in face yarn linear density; however with further increase in face yarn linear density, trans planar wicking decreases. Thus, it can be concluded that fabrics knitted with coarser yarns (PC3, PPC3, NC3) do not appear to be suitable choice at high activity level as such fabrics would result in skin wetness and damp feeling to wearer owing to high water absorbency and slow drying capability (characterized by lower water evaporation percentage).

N/C fabrics show the lowest value of trans planar wicking and water evaporation percentage. Thus, it can be concluded that plated fabrics with nylon in the back layer seem to be a suitable choice at low activity levels as the fabrics are permeable to passage of air and moisture vapor; however at high activity level characterized by the onset of sensible perspiration, N/C fabric may not be effective in rapid sweat transfer due to high water absorption, poor wicking property and slow drying (low water evaporation percentage). PP/C fabric however appears to be preferred at high activity levels, owing to lower water absorption, higher trans planar wicking and higher water evaporation percentage.

It can therefore be concluded from the observations of this study that polypropylene in back (next to skin) layers and face yarn linear density of 39.4 tex are good combination of fibre and yarn variables in designing the distinct face and back layers of plated knitted fabrics to be used at high activity levels.

References

1 Bivainyte A & Mikucioniene D, *Fibres Text East Eur*, 19 (2011) 64.
2 Fangueiro R, Filgueiras A & Soutinho F, *Text Res J*, 80 (2010) 1522.

3 Ozturk M J, Nergis B & Candan C, *Text Res J*, 81 (2011) 324.
4 Laing R M, Wilson C A, Gore S E, Carr D J & Niven B E, *Text Res J*, 77 (2007) 583.
5 Cimilli S, Nergis B, Candan C & Ozdemir M, *Text Res J,* 80 (2010) 948.
6 Ansari N & Kish M, *J Text Inst*, 3 (2000) 410.
7 Terliksiz S, Kalaoglu F & Eryuruk S H, *J Text Eng*, 19 (2012) 15.
8 Das B, Das A, Kothari V K, Fanguiero R & Araujo M, *Autex Res J*, 7 (2007) 100.
9 Zhang W, Li J, Chen W & Long S, *J Text Inst*, 90 (1990) 252.
10 Crow R & Osczevski R, *Defense Research Establishment Ottawa Report No. 1182*, (1993) 1.
11 Mehrtens D G & Mcalister K C, *Text Res J*, 32 (1962) 658.
12 Das B, Das A, Kothari V K, Fanguiero R & Araujo M, *J Eng Fiber Fabr,* 4 (2009) 20.
13 Das B, Das A, Kothari V K, Fangueiro R & Araujo M, *J Text Inst*, 100 (2009) 588.
14 Mhetre S & Parachuru R, *J Text Inst*, 101 (2010) 621.
15 Zhou L, Fang X & Li Y, *Fibres Text East Eur*, 83 (2010) 72.
16 Sampath M B, Mani S & Nalankilli G, *J Text Inst*, 41 (2011) 160.
17 Chaudhari S S, Chitnis R S & Ramakrishnan R, Water proof breathable active sports wear fabrics, http://www.sasmira.org /sportswear.pdf, (accessed on 23 March 2011).
18 Morton W E & Hearle J W S, *Physical Properties of Textile Fibres* (The Textile Institute, Manchester, U.K.), 1962, 170.
19 Fangueiro R, Goncalves P, Soutlnho F & Freitas C, *Indian J Fibre Text Res,* 34 (2009) 315.
20 Bedek G, Salaun F, Martinkovska Z & Devaux E, *Appl Ergon*, 42 (2011) 792.
21 Long H, *Int J Cloth Sci Technol*, 11 (1999) 198.
22 Y Jhanji, D Gupta & V K Kothari, *Indian J Fibre Text Res*, 40 (2015) 11.
23 Kissa E, *Text Res J*, 66 (1996) 660.