Analysis of Fabrics Structure on the Character of Wicking

Ramesh Babu V.[1], Ramakrishnan G., Ph.D.[1], Subramanian V. S., Ph.D.[3], Lakshmi Kantha, Ph.D.[2]

[1]Kumaraguru College of Technology, Coimbatore, Tamil Nadu INDIA

[2]Madha Engineering College, Chennai, Tamil Nadu INDIA

[3]Jaya Engineering College, Chennai, Tamil Nadu INDIA

Correspondence to:
Ramesh Babu email: salemramesh@yahoo.com

ABSTRACT

In this article, the effect of weave pattern on fabric wicking was analyzed. Weaves are distributed into two groups, i.e. weaves, the floats of which are distributed in even intervals throughout the entire surface of fabric, and horizontally striped weaves. The wickability properties of all tested fabrics are determined using a newly developed electronic vertical wicking tester. It was determined that the results of wicking horizontally striped fabrics were higher than those of weaves with evenly distributed floats. Washburn's equation obeyed quite well when the time constant is near 0.5. In fact, the time constant for plain and fancy twill weave were exponentially lower than those of other fabrics. This can be considered a measure of fabric rigidity.

Keywords: electronic vertical wicking, integrated fabric structure factor, wickability.

INTRODUCTION

Clothing has an important role in keeping the body comfortable by removing sweat. The flow of liquid in fiber assemblies, such as yarn and fabric, happens because of capillary forces [1].In the field of liquid sorption in a porous area, Washburn [2] has expressed the following equation:

$$h = a.t^{0.5} \quad (1)$$

where h is the wicking height (m): a, the capillary liquid transport constant and t, wicking time(s). Laughlin showed the need of correction in the exponent term in Eq. (1) and many researchers suggested that the exponent should be lower than 0.5. Hence, Laughlin generalized the Washburn's equation into the following form:

$$h = a.t^{k} \quad (2)$$

where k may have values lower than 0.5 for different types of fabrics. Eq. (1) shows that the capillary force causes the progress of liquid through a capillary channel. This capillary force depends on the radius of capillary channel and the contact angle between liquid and capillary channel as well as rheological properties of the liquid. Eq. (1) is used to interpret wicking behavior of textiles [3]. A variety of techniques and methods are used to study experimentally the liquid penetration into fabrics.

The first technique used consists of observing and measuring the liquid rise in textile structure by using a colored liquid [4, 5]. Perwuelz *et al.* [6] developed another method based on the analysis of CCD images taken during the capillary rise of colored liquid in yarns structure. The results obtained by image analysis technique depend on the resolution, the quality of images and the light source. Furthermore, the kinetics of water can be more important than those of dye and the diffusion coefficient found by this method presents the value of the diffusion coefficient of the dye, not that of the liquid. Moreover, the addition of the dye changes the surface tension of the liquid and modifies its velocity. Hsieh *et al*. [7, 8] and Pezron [9] in their studies used a balance to measure the impregnation liquid mass variation in the solid structure. This method is unable to determine the equilibrium height and the quantity of liquid absorbed by the textile at different heights.

Another method consists of measuring water transport along textile fibers by an electrical capacitance [10, 11]. This technique consists of the construction of an apparatus with a specially designed electrical amplifier circuit and condenser electrodes, between which sample fibers are set. This method is unable to determine the liquid content at different heights, and permits only a global view of the evolution of liquid transport.

The last technique is based on the electrical resistance principle where the liquid height was measured by using a single probe. This method is also unable to measure the liquid height at various levels [12]. In the present work, a technique based on open and closed electrical circuit principle has been used to determine the capillary height of liquid at various levels without dye with respect to time. This technique helps the in-depth study of the wicking behavior of the fabrics.

MATERIALS AND METHODS

To conduct the above mentioned experiments, the fabrics used were woven with projectile desk loom of Polyester/Viscose blend 65/35, 19.5 tex, 2 ply, warp setting 236 dm–1, weft setting 236 dm–1. The fabrics were woven in 12 different weaves as shown in *Figure 1*. The weaves were chosen in such a way that they could be woven with the same loom setting. The weave factor $P1$ of all chosen weaves was changed to the widest possible range (from 1 to 1.9). From the chosen weaves, six weaves (1, 2, 4, 5, 6, and 7) had floats evenly distributed through the full fabric surface, and six weaves (3, 8, 9, 10, 11, and 12) were horizontally striped.

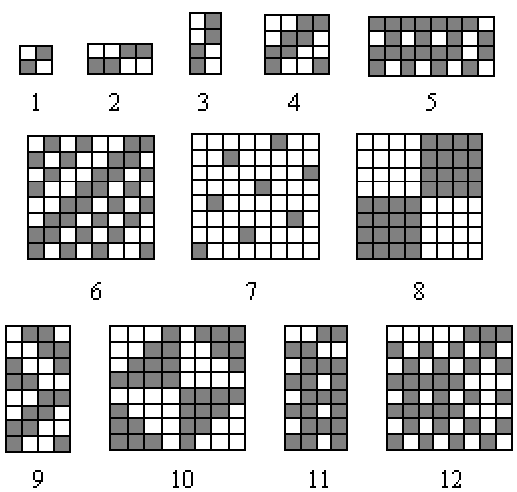

FIGURE 1. The weaves used in experiment. A1 – plain weave; A2 – weft rib; A3 – warp rib; A4 – twill 2/2; A5 – weft direction Bedford cord; A6 – fancy twill ; A 7 – sateen; A8 – basket weave; A9 – broken twill; A10 – crape weave; A11 – warp direction Bedford cord; A12 – mock leno.

Circuit Description

In this circuit, the probe is used to measure the water level seen in *Figure 2*. A test probe (test lead, test prod) is a physical device used to connect electronic test equipment to the device. All the probe leads are pulled high through the resistors. They are placed in different height levels. Then the probe outputs are given to 40106 hex schimitt trigger inverter [13].

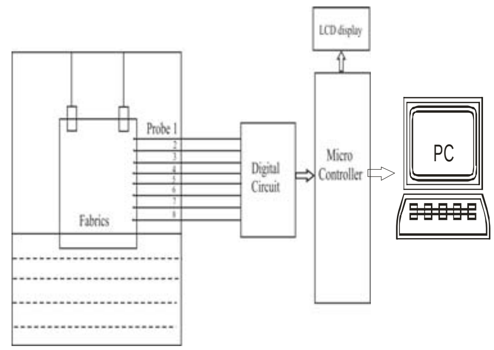

FIGURE 2. Experimental system.

Initially when the fabric is dry, the probe leads are not in touch with water. So, the probe leads are increased, and are in turn inverted to low through the hex inverter. When the water level is increased gradually, the touched probes become low which are inverted to high by the hex inverter. Then the corresponding output signal is given to a microcontroller in order to find the water level. The successive signals from opening and closing switches in this system are captured by computer (lab view software) to measure the liquid height with respect to the time [13].

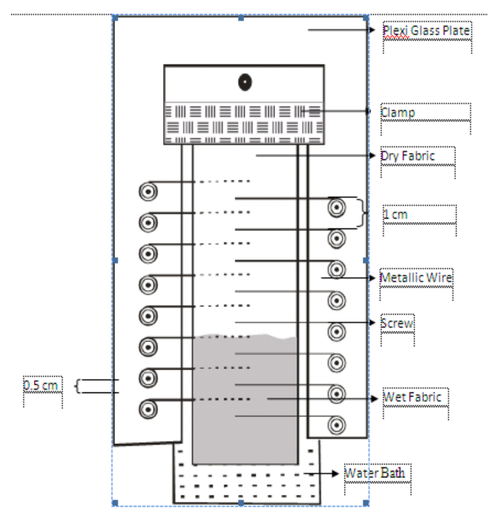

FIGURE 3. Principle of measuring liquid transport.

The fabrics have undergone the commercial scouring process. The sample (10’’ × 1’’) was prepared in warp and weft direction and then placed in a climatic chamber at the temperature of 27ºC and 65% RH. The test has been conducted using an Electronic vertical wicking tester (*Figure 3*) according to DIN 53924 method [14]. A strip of fabric was suspended vertically with its lower end (30mm) immersed in a reservoir of distilled water. The selected fabric, initially dry, is maintained vertically and partially immersed in a bath containing distilled water. The fabric support is composed of a plexi-glass plate where the screws are affixed every 1 cm on both the sides.

The metallic wires are extended halfway from the screws on both sides and touch the front and back sides of the fabric at regular intervals of one half centimeter. There are a total of eight probes that touch the front side of the fabric and another eight that touch the back side of the fabric alternately. The liquid height in fabric is deduced at different intervals experimentally from the signals given by the software program. Each sample was conducted using five tests to compute the average value. The time in seconds required for the water to reach 5 cm at an interval of 1cm along the strip is measured and noted. All wicking measurements were performed at 28°C - 30°C temperature (room condition) and 38 - 40% relative humidity.

RESULTS AND DISCUSSION

In order to establish the influence of fabric weave on fabric wickability, vertical wicking tests were carried out using fabrics of two types. The 12 woven fabrics and the wicking time in seconds (5cm height) for both warp and weft directions are shown in *Figure 4*. It was observed that the character of fabric wicking, whose floats are distributed evenly throughout the entire fabric surface, and of horizontally striped fabric are different.

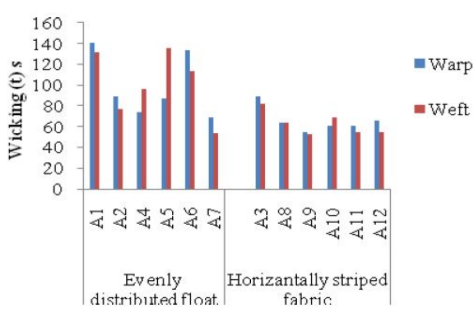

FIGURE 4. Effects of types of fabric on wicking

Figure 4 shows fabrics with evenly distributed float wicks slower and horizontally striped fabrics wicks faster. It is thought that this happens because the floats of threads in horizontally striped fabrics are placed on the edge of the horizontal stripes, and are distributed throughout the entire fabric surface. This irregular structure may be the reason why the rate of wicking is higher for the horizontally striped fabrics. There are slight variations observed in the rate of warp and weft way wicking, in some cases, the rate of weft way wicking is higher than that of warp way wicking. This may be due to the tension variations of warp and weft threads.

Two methods were used to analyze the wicking results obtained in this study. In the first method, from the vertical wicking results, the logarithm of the wicking time was plotted against the logarithm of the wicking height (*Figure 5*). It was found that the values of the time exponents in Washburn equation range between 0.39 and 0.49. In most of the cases, the time exponents in vertical wicking are near 0.5 which is the Washburn value. Values of time exponent (k) in vertical wicking are shown in *Table I* (Model assumed to calculate the time exponent k is: $H= a.t^{k,}$ where a is the constant; t, time; and H, distance travelled. The values of k are taken from *Table II*).

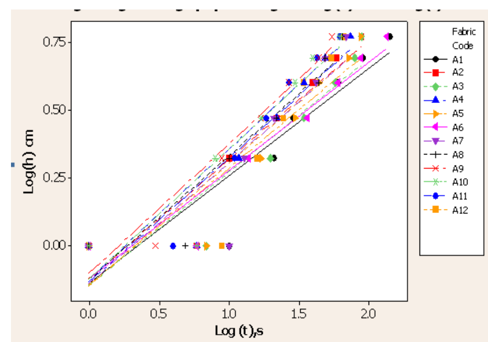

FIGURE 5. Regression graph plotted against log (h) vs. log (t).

TABLE I. Values of time exponent k in vertical wicking time for various fabrics.

Fabric Code	Fabric	Time exponent k (Warp)	Time exponent k (Weft)
A1	Plain weave	0.396	0.395
A2	Weft Rib weave	0.439	0.443
A3	Warp rib weave	0.415	0.440
A4	2/2 twill weave	0.459	0.430
A5	Bedford cord(Weft direction)	0.429	0.455
A6	Fancy Twill weave	0.398	0.410
A7	Sateen weave	0.446	0.460
A8	Basket weave	0.456	0.453
A9	Broken twill weave	0.479	0.483
A10	Crape weave	0.478	0.468
A11	Bedford cord (Warp direction)	0.479	0.495
A12	Mock leno	0.451	0.462

The higher k values are noticed for horizontally striped fabrics compared with evenly distributed floats. It also observed that the k values are increased for weft direction. It is noticed that the k values are 0.39 for plain and fancy twill fabrics. This denotes that the wicking rate for these fabrics are lesser compared with other fabrics and therefore, the values of k can also be taken as a measure of rigidity of fabrics, as well as wickability of the fabrics. *Table II* gives the correlation coefficient and regression equations for the 12 fabrics. (Model assumed is: Log (H) = k log *t* + constant0).

TABLE II. Regression equations of the form log (h) = klog *t* + constant and correlation coefficients for various fabrics.

Code	Fabric	Regression (Warp)	Coefficient (Warp)	Regression(Weft)	Coefficient (Weft)
A1	Plain weave	log(h) = 0.396(t) - 0.140	R^2 = 0.835	log(h) = 0.395(t) - 0.147	R^2 = 0.818
A2	Weft Rib weave	log(h) = 0.439(t) - 0.122	R^2 = 0.891	log(h) =0.443(t) - 0.137	R^2 = 0.859
A3	Warp rib weave	log(h) = 0.415(t) - 0.144	R^2 = 0.861	log(h)=0.440(t) - 0.145	R^2 = 0.850
A4	2/2 twill weave	log(h) = 0.459(t) - 0.135	R^2 = 0.877	log(h) =0.430(t) - 0.141	R^2 = 0.846
A5	Bedford cord (Weft direction)	log(h) = 0.429(t) - 0.143	R^2 = 0.862	log(h) =0.455(t) - 0.140	R^2 = 0.873
A6	Fancy Twill weave	log(h) = 0.398(t) - 0.123		log(h) = 0.410(t) - 0.128	R^2 = 0.901
A7	Sateen weave	log(h) = 0.446(t) - 0.139	R^2 = 0.782	log(h) = 0.460(t) - 0.146	R^2 = 0.745
A8	Basket weave	log(h) = 0.456(t) - 0.125	R^2 = 0.899	R^2 = 0.909	R^2 = 0.864
A9	Broken twill weave	log(h) = 0.479(t) - 0.104	R^2 = 0.951	log(h) = 0.483(t) - 0.104	R^2 = 0.950
A10	Crape weave	log(h) = 0.478(t) - 0.123	R^2 = 0.865	log(h) = 0.468(t) - 0.132	R^2 = 0.873
A11	Bedford cord (Warp direction)	log(h) = 0.479(t) - 0.124	R^2 = 0.916	log(h) = 0.495(t) - 0.117	R^2 = 0.916
A12	Mock leno	log(h) = 0.451(t) - 0.148	R^2 = 0.793	log(h) = 0.462(t) - 0.147	R^2 = 0.749

In the second analysis, the wicking height was plotted against the square root of time and the correlation coefficient and regression equations were computed.

Table III gives the values of slope and intercept (Model assumed is: $h=Kt^{0.5}$ + constant, where K is the slope). It is observed that the slopes of plain and fancy twill are lower compared to other fabrics. This indicates lesser rate of wicking. It noticed that the horizontally striped fabrics slopes shows higher values compared with the evenly distributed floats. This denotes that the rate of wicking is higher for the horizontally striped fabrics.

The correlation between wicking height and square root of time shows higher values compared to the logarithm method.

TABLE III. Regression equations of the form $h = k\ t^{0.5}$ + constant and correlation coefficients for various fabrics.

Fabric Code	Fabric	Regression (Warp)	Coefficient (Weft)	Regression (Weft)	Coefficient (Weft)
A1	Plain weave	$h = 5.320(t)^{0.5} - 2.939$	$R^2 = 0.987$	$h = 5.507(t)^{0.5} - 3.955$	$R^2 = 0.985$
A2	Weft Rib weave	$h = 6.774(t)^{0.5} - 2.340$	$R^2 = 0.990$	$h = 7.001(t)^{0.5} - 4.197$	$R^2 = 0.980$
A3	Warp rib weave	$h = 6.145(t)^{0.5} - 4.284$	$R^2 = 0.973$	$h = 6.884(t)^{0.5} - 4.642$	$R^2 = 0.977$
A4	2/2 twill weave	$h = 7.350(t)^{0.5} - 3.793$	$R^2 = 0.985$	$h = 6.413(t)^{0.5} - 3.497$	$R^2 = 0.984$
A5	Bedford cord (Weft direction)	$h = 6.462(t)^{0.5} - 4.026$	$R^2 = 0.983$	$h = 5.263(t)^{0.5} - 0.962$	$R^2 = 0.996$
A6	Fancy Twill weave	$h = 0.415(t)^{0.5} + 9.621$	$R^2 = 0.922$	$h = 0.505(t)^{0.5} + 8.327$	$R^2 = 0.939$
A7	Sateen weave	$h = 7.496(t)^{0.5} - 5.550$	$R^2 = 0.954$	$h = 8.328(t)^{0.5} - 7.603$	$R^2 = 0.923$
A8	Basket weave	$h = 7.310(t)^{0.5} - 3.259$	$R^2 = 0.975$	$h = 7.348(t)^{0.5} - 4.836$	$R^2 = 0.958$
A9	Broken twill weave	$h = 8.116(t)^{0.5} - 2.584$	$R^2 = 0.992$	$h = 8.200\ (t)^{0.5} - 2.616$	$R^2 = 0.991$
A10	Crape weave	$h = 8.058(t)^{0.5} - 3.471$	$R^2 = 0.979$	$h = 7.641(t)^{0.5} - 3.653$	$R^2 = 0.984$
A11	Bedford cord (Warp direction)	$h = 7.988(t)^{0.5} - 3.441$	$R^2 = 0.987$	$h = 8.432(t)^{0.5} - 2.983$	$R^2 = 0.987$
A12	Mock leno	$h = 7.631(t)^{0.5} - 6.376$	$R^2 = 0.956$	$h = 8.411(t)^{0.5} - 7.796$	$R^2 = 0.926$

CONCLUSION

A good linear relationship between the wicking height and the square root of wicking time is found. Another relationship in which the wicking height is plotted against square root of time shows that the slopes are lower for plain and fancy twill fabric which implies the rigidity of the fabrics.

Washburn's equation is obeyed quite well when the time constant is near 0.5. In respect of plain and fancy twill fabrics, the time exponent is significantly lower compared to other fabrics, which indicates poor wicking rates of those fabrics.

The values of time constant k show an increase in value for weft direction wicking and horizontally striped fabrics indicating the improvement in their wickability. In view of this fact, the time constants for plain and fancy twill fabrics are exceptionally lower than those of other fabrics, and can be considered as measures of rigidity of the fabrics.

The correlation coefficient is higher when the graph plotted against height versus square root of time is compared with the logarithm method.

REFERENCES

[1] Kissa E, *Text Res J*, 66 (10) (1996) 660.

[2] Washburn E W. *Phys Rev*, 17 (1921) 273.

[3] Ansari N, *The effect of the structure of fibrous assemblies on wicking*, PhD thesis, Textile Engineering Department, Amirkabir University of Technology, Iran, 2000.

[4] Kawase T, Sekoguchi S, Fujii T & Mingawa M, Spreading of liquids in textile assemblies, Part I: Capillary spreading of liquids, *Text Res J*, 56 (7) (1986) 409-414.

[5] Kawase T, Sekoguchi S, Fujii T & Mingawa M, Spreading of liquids in textile assemblies, Part II: Effect of softening on capillary spreading, *Text Res J*, 56 (10) (1986) 617-621.

[6] Perwuelz A., Mondon P. & Cazé C., Experimental study of capillary flow in yarns, *Text Res J*, 70 (4) (2000) 333-339.

[7] Hsieh Y & Yu B, Liquid wetting, transport, and retention properties of fibrous assemblies, Part I: Water wetting properties of woven fabrics and their constituent single fibers, *Text Res J*, 62 (11) (1992) 677- 685.

[8] Hsieh Y & Yu B, Liquid wetting, transport, and retention properties of fibrous assemblies, Part II: Water wetting and retention of 100% and blended woven fabrics, *Text Res J*, 62 (12) (1992) 697-704.

[9] Pezron I., Bourgain G., & Quéré D., Imbition of a fabric, *J Colloid Interface Sci.*, 173 (1995) 319-327.

[10] Ito H & Muraoka Y, Water transport along textile fibers as measured by an electrical capacitance technique, *Text Res J*, 63 (7) (1993) 414- 420.

[11] Tagaya H., Haikata J., Nakata K., & Nishizawa K, Measurement of capillary rise in fabrics by electric capacitance method, *Sen-i Gakkaishi*, 47 (1987) 422-430.

[12] Nath Jyoti, Patil P G & Shukla K., Design and development of multipurpose absorption rate meter, *J. Agricultural Engineering*, 38 (2) (2001) 134-140.

[13] Ramesh Babu V., Koushik C V, Lakshmi Kantha C B & Subramaniam V S, Study of capillary rise in woven fabrics by electrical principle, *Indian J. Fibre & Textile Res*, 36, (2011) 99-102.

[14] Das Brojeswari, Das A., Kothari V K, Fangueiro R., and Araujo M., “Effect of fiber diameter and cross-sectional shape on moisture transmission through fabrics”, *Fibers Polymers*, Vol.9, No.2, 2008, pp.225-231.

AUTHORS’ ADDRESSES
Ramesh Babu V
Ramakrishnan G., Ph.D.
Kumaraguru College of Technology
Saravanampatti
Coimbatore, Tamil Nadu 641049
INDIA

Lakshmi Kantha C. B., Ph.D.
Madha Engineering College
Kuntrathur Somamangalam
Chennai, Tamil Nadu 600069
INDIA

Subramaniam V. S., Ph.D.
Jaya Engineering College
Mduravoil
Chennai, Tamil Nadu 602024
INDIA