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The Wicking Behavior of Fabrics

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Abstract

This study examined the capillary action flow of water in horizontal samples of fabrics. The following results were obtained:

1) The distance of movement of a drop of water (S), when the elapsed time is represented by t, was demonstrated to a have a directly proportional relationship to the related values of $t - S^2$.
2) When the surface tension of the drop of water is (γe), the viscosity of the liquid is (η) and contact angle is θ, the relationships of these factors, as obtained based on experimental results could be obtained for various different types of fabric and t values for these different types of fabric agreed closely with the size of the respective S values.

$$S^2 = \frac{\gamma_e \cdot \cos\theta}{2\eta} \cdot t$$

3) Therefore, regarding the relationships referred to in 2) above, it is thought that there is a need to take into consideration the effects of the capillary tube r values, The values referred to are explained by the following formula:

$$S^2 = \frac{r \cdot \gamma_e \cdot \cos\theta}{2\eta} \cdot t$$

Key words: capillary action, surface tension, contact angle

1. INTRODUCTION

The wetting of fabrics used for clothing, in general, can be divided into washing (including soaking and rinsing), absorption of sweat in the case of underwear and spotting as involves capillary wetting. In this study, the main type of wetting discussed is the last type, wetting involving capillary action. However, there are hygiene factors involved with the absorption of sweat and also other important matters in the case of spotting such as maintaining the outer appearance of the fabric and damage to the fabric.

Capillary wetting begins when water adheres to thread and fiber surfaces and then moves into gaps between the elements of the threads and fibers, then penetrates further until capillary action phenomena start to occur. Here, the discussion will take up the stage where water has begun to enter the gaps between the threads or the fibers of the fabric. In this case, where the penetration of water involves the gaps between the threads and the fibers, this level of wetting does not involve any particular problems. However, because these gaps are irregular and difficult to deal with, there have been almost no studies carried out concerning this type of wetting of fabric.

Therefore, the main objective of this study was to obtain basic knowledge of this capillary-type wetting phenomena. However, in the case of this study, such testing methods for measuring wetting as the extent of penetration of the water over a given period or time or measuring the area where wetting occurred were not used. Instead the entire process of the wetting as such was allowed to run its course and this process was examined in detail. In other words, observations were repeated at very short intervals of time with the aim of capturing the unfolding of this wetting process.

2. TEST SAMPLES AND TESTING METHODS

2.1 Test samples

The samples of fabrics used for the testing included basic plain-woven materials made of cotton, wool, silk, rayon and nylon. Details are indicated in Table 1.

2.1.1 Pre-treatment of the fabric test samples

Capillary action phenomena basically involves the surface tension of the water and the contact angle of the water vis-à-vis the sample. Therefore, it is very

Table 1 Details of samples

Sample	Density (1/cm)		Count (d)	
	Warp	Filling	Warp	Filling
Cotton	33.0	27.5	30	36
Wool	28.3	27.5	52	68
Silk	56.5	39.7	21	21
Rayon	38.0	25.0	120	120
Nylon	61.3	40.5	50	50
Tetoron	60.3	39.0	50	75

important to carry out careful observations concerning the contact angle. However, such factors as impurities or the presence of grease have a very significant effect on contact angle. As a means of removing such factors, the following pre-treatment of the fabric test samples was carried out.

Using a 0.3% solution non-ion type surfactant ("Inogen" EA – 126 made by Daiichi Kogyo, Ltd.), the samples were pre-treated by washing them for a period of 10 minutes at a temperature of 70°C. This process was carried out two times. The first time, for this washing process only, washing soda was also added to the solution (Na_2CO_3 at 0.05%). In addition, after both the first and second washings, the samples were rinsed with an ample amount of warm tap water and distilled water (40 °C).

2.1.2 Making the samples

The fabrics that were pre-treated using the method described above were cut into strips 500mm in length (in the direction of the warp) and 20mm in width (in the direction of filling). Therefore, during the experiments, the water was transmitted in the direction of warp.

In addition, the reason for cutting the samples into 20mm widths will be explained in section 3.1.1.

2.2 Test equipment and testing methods

In order to measure the movement of the water in the test fabric, the test equipment indicated in Figure 1 was prepared. The surface of the glass plate used with this equipment was coated with paraffin and a glass container was used to hold penetration liquid. An adjustable support jack was used to adjust the elevation of this glass container and also functioned as a scale for measuring the movement of the water. As can be seen from this figure, first the glass plate must be adjusted so that it is absolutely level by using a spirit level. Then, so that the penetration liquid surface and the elevation of glass plate are the same, the upper edge of the glass

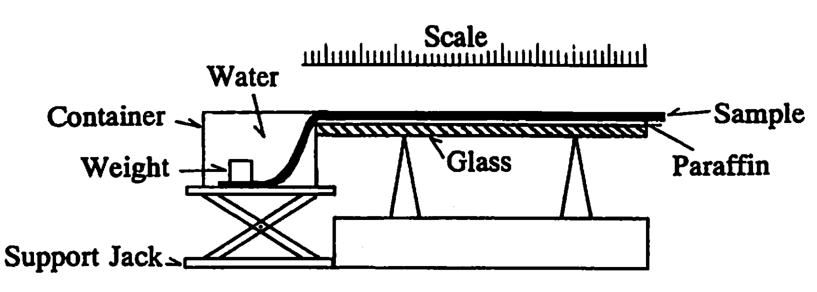

Fig.1 The test Equipment

container is aligned with the height of the glass plate by using the adjustable support jack. Next, the gap between the glass container and the glass plate is filled with paraffin and the scale is attached in position. With this last step, the equipment is adjusted and ready for use.

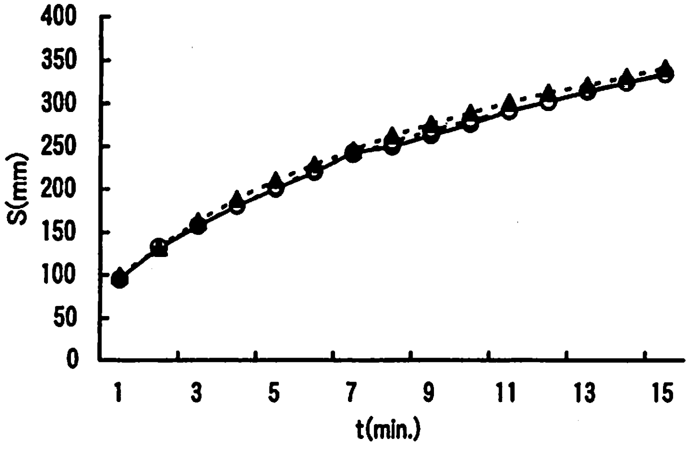

Fig.2 The effects of the specific width of the sample on the movement of drops of water

—●— ;20mm, - -○- - ;30mm, · · ▲ · · ;40mm

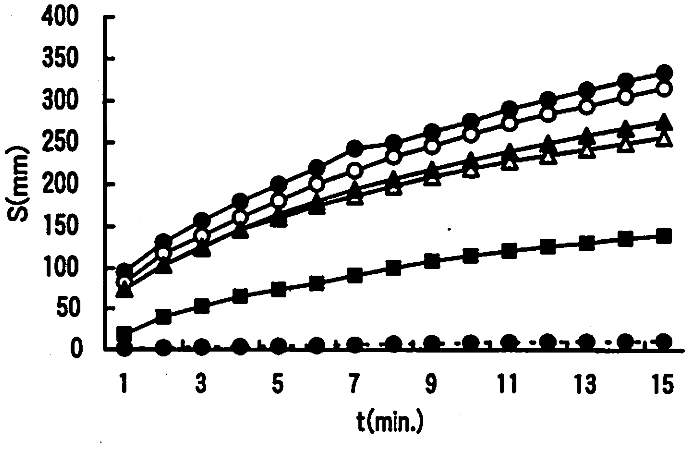

Fig.3 The t-S curve for the different types of fabrics listed in Table 1

—●— cotton, —○— rayon, —▲— silk, —△— nylon,

—■— tetoron, --●-- wool

After these conditions have been met, a fabric sample is put in place and when the glass container becomes completely filled with penetrating liquid, the measurement of elapsed time is begun and the penetration distance is measured once every minute.

In addition, during these experiments, the penetration liquid used consisted of 500cc of distilled water containing Mikethren red (0.5g) that was heated to 40 °C and left to cool for 10 minutes, after which it was used for the respective test.

3. RESULTS OF THE TESTING AND RELATED COMMENTS

3.1 The movement of water at the macro-level.

This section will discuss the movements of the water that exhibited capillary action phenomena within the fabric sample that could be observed by the naked eye, and the related surrounding phenomena.

3.1.1 The effects of the specific width of the sample on the movement of drops of water.

In experiments of this kind, it is necessary to discuss the effects of the width of the sample on the movement of the water within the test sample.

In Figure 2, a preliminary 100% cotton sample (Sample A) was cut into test samples of 20mm, 30mm and 40mm in width and effect on the distance traveled by the water (S) and elapsed time were studied. Results showed that there appeared to be little difference between them so that the width of the sample did not have significant effect on these results. Therefore, for the purposes of the experiments that followed, test samples 20mm in width were used.

3.1.2 Tendencies related to capillary wetting phenomena among fabrics made of different basic materials

Figure 3 shows the t – S curve for the different types of fabrics listed in Table 1. Usually, it is important to have data concerning the number of fibers (and their thread configuration) and their design features, thickness, density, etc. However, it is nearly impossible to obtain complete data of this nature. Therefore, this Figure has been generated to compare the t – S curves and does not, of course, indicate the complete situation. However, all the various sample types listed in Figure 1 are standard types of fabric. Taking this into consideration, the comparison of the t – S curves in Figure 3 can be said to be quite interesting.

As can be seen from the t – S curves in Figure 3, as an overall tendency, with the elapsing of time, it appears that the distances tend to diminish. However, the greatest capillary phenomena occurred in the case of cotton and rayon. These fabrics were followed by silk and nylon. The fabrics that showed the lowest level of capillary action phenomena were Tetron and wool.

Table 2 indicates the contact angle[1),2)] measurements for each of the fabric types. For capillary tubes with similar diameters, the capillary force (F) causing the water to move is in direct proportion to the cosine of the contact angle cos θ. Therefore, the larger the θ values shown in this table, the smaller the F values. As was stated above, the samples used for this study, the density of the threads and fibers of the various samples differ so that it is difficult to say which have capillaries with similar diameters. However, for the t values in Figure 3, as compared to their respective S values, the overall order of size of S values appears to correspond with the cosines of the contact angles indicated in Table 2. In other words, the capillary force related movement of water through the fabric appears to be related in some way to the wet-ability of the basic fibers used for respective fabrics.

3.1.3 t – S Curves

For capillary tubes with similar size diameters, they exhibited capillary phenomena as a level array that caused the water to move a distance of S over a time of t. It is known that this can be expressed by the following physics equation:

$$S^2 = \frac{r \cdot \gamma e \cdot \cos\theta}{2\eta} \cdot t \qquad \cdots\cdots\cdots\cdots \quad (1)$$

where, S is the distance traveled by the water, r is the diameter of the capillary tubes, η is a coefficient of the viscosity of the liquid, t is the elapsed time, γe is the surface tension of water and θ is the contact angle.

However, formula (1) can be applied only when the all the respective capillary tubes are arranged horizontally. In cases where the threads are composed of complex arrangements of fibers, the formula cannot be used. However, if the expression: $r \cdot \gamma e \cdot \cos\theta / 2\eta$ = k(const.) is used, the relationship of t and in (1) can be seen to be:

Table 2 Contact angle to water

Fiber	Cotton	Wool	Reyon	Naylon	Tetoron
Contact angle (°)	47~59	81~55	38	64~78	53

$$S^2 = k\,t \qquad \cdots\cdots\cdots\cdots \quad (2)$$

thus, t – S and is a straight-line relationship that can be seen to exist the between the

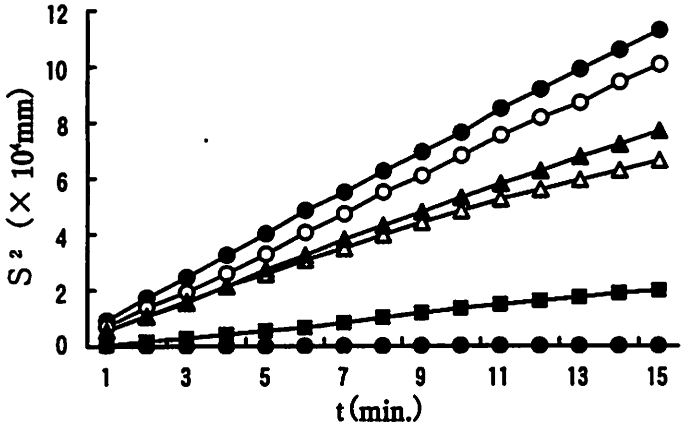

Fig.4 The t-S curve values in Fig.3 converted to t-S^2 values
–●– cotton, –○– rayon, –▲– silk, –△– nylon,
–■– tetoron, --●-- wool

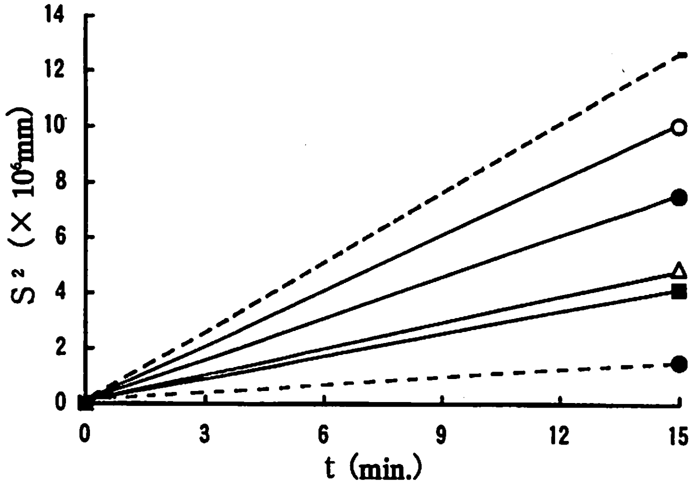

Fig.5 The θ values in Table 2 and the values generated by the expression γ· e :73dyn/cm, η :0.00921g/cm・sec are used (4) to reflect the differences between the various types of fibers
------ relationships in (3), –●– cotton, –○– rayon,
–▲– silk, –△– nylon, –■– tetoron, --●-- wool

$t - S^2$ values. Therefore, the author has attempted to confirm whether this will apply in the case of differing fabrics.

Figure 4 shows the t – S curve values in Figure 3 converted to $t - S^2$ values. From this figure, it can probably be agreed that the relationship indicated by expression (2) above exists.

Next, a discussion of k as it appears in expression (2) follows. Among the various factors that make up k, such factors tend to refer only to the physical quality of the water, such as $\gamma e / 2\eta$ in the $t - S^2$ relationship and this these factors do not reflect the effects of differences in the types of fabrics involved. In other words, if

$$S^2 = \frac{\gamma e}{2\eta} \cdot t \qquad \cdots\cdots\cdots\cdots \qquad (3)$$

is used as the basic expression, then it is easy to examine the curves shown in Figure 4 for $t - S^2$. Here, the difference between formula (1) and the factors in the right side of formula (3) lack r and cos θ. In the case of the former, the diameter of the capillaries and the composition of the threads and fibers have a direct relationship. In the case of the latter, depending on the type and composition of the fibers that make-up the fabric and the water exhibit their own characteristics.

Next is a formula that includes factors reflecting different cos θ values for different types fabric composition and different types of fibers.

$$S^2 = \frac{\gamma e \cdot \cos\theta}{2\eta} \cdot t \qquad \cdots\cdots\cdots\cdots \qquad (4)$$

In Figure 5, the θ values in Table 2 and the values generated by the expression $\gamma e = 73$dyne/cm, $\eta = 0.00921$g/cm·sec are used (4) to reflect the differences between the various types of fibers. In addition, the relationships in (3) above are also shown by the dotted lines in the figure.

The $t - S^2$ relationships from Figure 5 derived using (3) that do not reflect differences in types of samples, by adding the cos θ factor, produce the $t - S^2$ values as expressed in formula (4). In the same way, it can also be seen that the data can be grouped by the different basic fibers used to make sample fabrics. What's more, the order of size of S^2 values as related to t values agrees well with the actual results of measurements shown in Figure 3. This fact helps to explain the meaning of 3.1.2. In addition, by comparing formula (1) and formula (4), it can be seen that formula (4) indicates that the $t - S^2$ values are generated by treating r as a constant.

Thus, the t – S^2 values generated using formula (4) appearing in Figure 5 are a case where composition of the fabric and its design have been treated as constants and only the materials of the fibers have been varied. However, this can be termed an example of a capillary action type wetting for an ideal fabric.

At this point, when Figure 4 is compared to Figure 5, it can be seen that the differences between the various test fabrics differ by several orders of magnitude for the proscribed S^2 values and their respective t values. As was mentioned above, the relationships of the t – S^2 values as shown in Figure 5 are those generated by formula (4) when r was treated as a constant. Therefore, the factor r contained in formula (1) as it involves questions related to capillary action wetting, can be seen to have a very large significance.

Table 3 shows the results of calculations of values shown in Figure 4 above for the measurement values for the different types of fabric samples. For that Table, it can be seen that the values of r are different for each different fabric type. Thus, one is forced to consider the effects of the composition of the each type of fabric is related to the different r values for the capillary tube diameters.

Table 3 The calculation of $\cos\theta$, S^2/t, r

	$\cos\theta$	S^2/t (cm/sec.)	r (cm)
Cotton	0.682~0.515	1.276	$4.72 \times 10^{-4} \sim 0.63 \times 10^{-4}$
Rayon	0.788	1.124	3.59×10^{-4}
Nylon	0.438~0.342	0.778	$4.48 \times 10^{-4} \sim 5.74 \times 10^{-4}$
Tetoron	0.391~0.259	0.218	$1.40 \times 10^{-4} \sim 2.12 \times 10^{-4}$
Wool	0.156~0.087	0.001	$1.90 \times 10^{-6} \sim 3.55 \times 10^{-6}$

(γe ; 73dyne/cm, η ; 0.0092g/cm · sec.)

4. CONCLUSION

This study examined the capillary action flow of water in horizontal samples of fabrics. The following results were obtained:

1) The distance of movement of a drop of water (S), when the elapsed time is represented by t, was demonstrated to a have a directly proportional relationship to the related values of t – S^2.
2) When the surface tension of the drop of water is (γe), the viscosity of the liquid

is (η) and contact angle is θ, the relationships of these factors, as obtained based on experimental results could be obtained for various different types of fabric and t values for these different types of fabric agreed closely with the size of the respective S values.

$$S^2 = \frac{\gamma_e \cdot \cos\theta}{2\eta} \cdot t$$

3) However, for the relationships referred to in 2) above, for an S^2 value for a respective t value as such, there were large differences in measured values. Therefore, regarding the relationships referred to in 2) above, it is thought that there is a need to take into consideration the effects of the capillary tube r values, The values referred to are explained by the following formula:

$$S^2 = \frac{r \cdot \gamma_e \cdot \cos\theta}{2\eta} \cdot t$$

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