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In the study, it is aimed to experimentally and statistically compare the results of selected three different water absorption test methods and for this purpose, terry fabrics having different physical properties and pretreated with sodium hydroxide were used as samples. Correlation and curve estimation analyses were carried out using the obtained hydrophilicity values and degrees as input data. As a result, it was determined that 50% of the samples have the same hydrophilicity degree in three test methods, and a high correlation was detected between the hydrophilicity degrees obtained by water flow and drop tests. In addition, generally, it was concluded that increasing pile height and weight in water have positive effects on hydrophilicity property.

Keywords: terry fabrics; physical properties of towels; hydrophilicity test methods

Introduction

For textile samples, hydrophilicity can be defined as the ability of a material to remove water on a surface through absorption. Hydrophilicity degree can be evaluated by determining the amount of absorbed water at a constant time or determining the absorption time of a constant amount of water. High hydrophilicity is the most important property that terry fabrics must have due to their use in drying purpose. The main property of terry fabrics distinguishing them from other textile products is the structure called pile on their surface, and the reason for creating these structures through additional yarn system is to increase the surface area in contact with water of textile product and thus hydrophilicity degree.

There are many test methods developed for detecting water absorption degree of textile materials in the form of fiber, yarn, or fabric. For example, sinking and drop tests by TS 866 1985 numbered standard, potassium chromate test by DIN 53923 1978, standard method for surface water absorption of terry fabrics (water flow) by ASTM D 4772-97 1997, and internal test method (static water absorption) by standard based on the Bureau Veritos Consumer Products Services BVS 1008 (Karahan & Eren, 2006).

In the literature, there are various studies performed with one or more of these test methods. Petrulyte and Baltakyte (2009) investigated the effects of pile height, cloth thickness, laundering process, and chemicals used in laundering (fabric softener, washing agent, etc.) on static water absorption property. Karahan and Eren (2006) experimentally analyzed the effects of fabric parameters on static water absorption property. Accordingly, terry fabrics made of two-ply ring-carded yarn were determined as having the highest absorption degree; absorption increases with decreasing density, while water absorption improves with increasing pile height.

Das, Das, Kathari, Fanguiero, and Araujo (2009) investigated the effects of hydrophilicity degree on air permeability and water vapor permeability properties of fabrics woven with widely used polyester/viscose mixture. As a result, it was determined that water vapor permeability increases with an increase in the hydrophilicity degree of the material, and hydrophilic proportion has an adverse effect on the liquid moisture transmission behavior. In the study of Aksoy and Kaplan (2011), liquid transfer mechanisms within textile materials were introduced in detail from the level of fiber to the finished product, considering the effects of material characteristics, process parameters, and finishing applications. Kim, Lee, Lim, and Jeon (2003) have determined the sorption characteristics of pile and non-pile fabrics with Gravimetric Absorbency Testing System apparatus from their properties of weight, density, thickness, pore size, and fineness.

The aim of the study is to investigate the similarities between the selected hydrophilicity test methods

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experimentally and statistically. For this purpose, three hydrophilicity test methods, widely used in the sector, were selected and applied to 30 different terry fabric samples; consequently, the size and direction of relations among test methods were determined by correlation analysis. In addition, equations were established by curve estimation analysis to predict water absorption degree through weight per square meter (grammage) and pile height parameters without performing tests.

Materials and methods

Primarily, a comprehensive experimental study was carried out; and for this purpose, 30 terry fabrics with different physical properties were used. The main reason for using terry fabrics as samples is that hydrophilicity property is most required in terry fabrics among textile products. The terry fabric samples were woven in PICANOL terry weaving machine with 100% cotton yarn. After weaving, the woven fabrics were pretreated under mill conditions. Firstly, the fabrics were washed at 60°C for 5 min. Then, samples were treated with caustic (48°C) and hydrogen peroxide at 98°C for 30 min and lastly, they were washed and the pH value was adjusted to 10. The selected physical properties of terry fabric samples (yarn count, weft and warp density, grammage, and pile height) were experimentally determined based on the TS (Turkish Standards) (TS 255, 1989; TS 629, 1991; TS 251, 1991; TS 250, 1996).

In addition, water absorption degrees of all samples were determined using the selected three different hydrophilicity test methods (drop test, sinking test, and water flow test). Drop and sinking tests are selected as they are commonly used for towel, and these methods are recommended by TS for terry fabrics. In addition to this, water flow test is chosen as it is based on the standard developed by ASTM (American Society for Testing and Materials) for towel products (ASTM D 5433-00:2000 2000). The basic principles of these tests are shortly described below:

- Water flow test (ASTM D 4772-97 1997): this method is based on the determination of water quantity absorbed during the flow of certain amount of water (50 ml) in a certain period of time (25 s) from the sample (20 × 20 cm) surface put under a burette at 60° angle and placed in a hoop. In this test, water flows from the upper middle of the fabric to the lower middle, and some of this water is absorbed during this process, while the rest is collected in a case under the setup. The amount of absorbed water is calculated by subtracting the amount of water collected in the case from first weight. This process is repeated for six samples and their arithmetic mean is taken. Higher amount of absorbed water means better hydrophilicity.
- Drop test (TS 866 1985): it is based on the period of time required for the absorption of water drops left on the product surface, horizontally placed in hoop from a certain height (10 mm) by means of a burette. A total of 10 drops are dripped on each fabric sample and their arithmetic mean is taken. Shorter absorption time means better hydrophilicity.
- Sinking test (TS 866 1985): in this method, a sample having 75 × 75 mm size is let into a beaker filled with water from a certain height (10 ± 3 mm) and the time is determined until the sample disappears from the surface. The process is repeated for three samples and their arithmetic mean is calculated. Then, the result is evaluated in a way similar to the drop test.

In the drop test, one of the two methods standardized by TS Institute, it is more difficult to obtain a numeric value when it is applied to terry fabrics having high water absorption capacity because of very quick absorption. For this reason, sinking test could yield more precise results with terry fabrics having this structure. On the other hand, drop test could provide a practical test opportunity to numerically determine the hydrophilicity degree of terry fabrics with low water absorption capacity as it takes longer period of time for this type of terry fabrics to sink by absorbing water in sinking test. Absorption of a drop takes much shorter time than a piece of certain sized fabric to sink through absorbing water.

Critical values, determined by standards and used to evaluate the results of the three test methods, are given in Table 1. In this table, high hydrophilicity degree is represented with “1”, moderate hydrophilicity degree with “2”, and low hydrophilicity degree with “3”.

Table 1. The critical value for test methods (TS 866, 1985; TS 629, 1991; ASTM D 4772-97 1997; Lyle DS. 1977).

Test methods	High hydrophilicity degree (1)	Moderate hydrophilicity degree (2)	Low hydrophilicity degree (3)
Drop test	0–2.5 s	2.6–5 s	⩾ 5.1 s
Sinking test	0–50 s	51–100 s	⩾ 101 s
Water flow test	⩾ 5.1 g		0–5 g

In addition to the experimental study carried out using flow, drop, and sinking tests, various statistical analyses were also applied to the data obtained from it. In the statistical analysis of test results, correlation and curve estimation analyses were used.

Results and discussion

Experimentally determined physical sizes of terry fabric samples are collectively given in Table 2. Accordingly, weights per square meter of the samples change between 468 and 771 g/m^2, while pile heights change between 5.7 and 11. Pile height is represented as the ratio of the ground warp yarn length to the pile warp yarn length in a certain fabric length; and because of this reason pile height is a non-dimensional parameter. Special attention is given to keep grammage and pile height in wide intervals to increase the validity of study results.

In addition to physical properties of samples, hydrophilicity degrees were also experimentally determined with three different test methods and the results are given in Table 3. The results of the water flow test (except for six samples) changed between 0.19 and 1.56; in other words, quite close values were obtained with this method. However, the results of drop and sinking tests changed in quite wider intervals. Furthermore, the hydrophilicity degrees determined, based on Table 1, are given in this table beside hydrophilicity values. As mentioned earlier, “1” indicates high hydrophilicity degree, while “3” represents low hydrophilicity degree.

According to the water flow results, it is seen that the hydrophilicity degrees of six samples are “high”. Drop test results demonstrate that three samples have “high” hydrophilicity degree and three samples have “moderate” hydrophilicity degree. On the other hand, sinking test results indicate that 11 samples have “high” hydrophilicity degree, while seven samples have “moderate” hydrophilicity degree. When the three test results are concurrently evaluated, 15 samples have same hydrophilicity degree in the three test methods and 18 samples have similar hydrophilicity degrees in water flow and sinking test methods. Furthermore, 27 samples have the same hydrophilicity degrees in water flow and drop test methods. This

Table 2. Physical properties of samples.

Sample no.	Pile warp yarn count (Ne)	Ground warp yarn count (Ne)	Weft yarn count (Ne)	Weight per m^2 (g/m^2)	Weft density (weft/cm)	Warp density (warp/cm)	Pile height (−)
1	18.4	10.7	12.30	515.43	37.0	53.0	7.60
2	17.6	10.6	12.30	503.70	34.6	52.6	8.10
3	18.2	10.6	12.30	619.56	39.3	56.3	9.30
4	18.1	10.6	12.30	519.08	37.6	52.3	8.20
5	17.6	8.10	12.10	608.97	40.6	51.3	10.5
6	10.9	8.10	12.10	678.86	34.3	55.0	6.20
7	17.8	10.7	17.29	673.52	36.3	61.0	9.70
8	17.5	10.4	17.01	529.83	37.0	53.0	8.60
9	18.2	10.3	14.59	771.28	40.6	64.0	11.0
10	13.9	10.3	16.50	668.40	37.0	55.0	8.60
11	17.4	10.6	12.80	692.53	40.3	63.3	9.00
12	17.4	10.5	12.01	724.72	42.3	57.0	10.7
13	18.1	10.6	18.20	503.15	40.6	52.0	7.90
14	17.2	8.50	10.60	692.56	37.0	54.6	9.90
15	15.4	10.9	17.10	624.11	37.3	55.3	9.30
16	17.5	10.9	12.80	659.87	40.6	62.6	9.10
17	17.5	10.5	17.30	538.67	35.3	54.3	8.90
18	16.3	11.0	13.00	664.57	37.3	55.3	9.60
19	17.6	10.6	17.40	467.76	38.0	54.0	6.70
20	17.9	10.8	13.00	626.38	37.3	56.6	9.80
21	17.5	11.0	17.00	500.33	35.0	52.3	7.90
22	17.2	10.8	12.90	631.51	37.6	54.3	9.50
23	17.5	10.7	17.20	471.66	35.3	53.3	7.00
24	18.0	10.6	12.80	600.42	38.0	55.6	8.80
25	18.5	11.0	10.70	632.71	41.6	53.0	9.70
26	17.4	10.8	16.90	558.09	34.3	53.6	8.50
27	17.2	11.1	12.70	598.50	37.3	55.6	8.60
28	10.7	10.7	16.60	586.59	39.0	54.3	5.70
29	13.2	10.7	17.10	522.08	39.0	51.3	6.20
30	10.7	10.4	16.90	568.58	40.0	52.0	6.10

Table 3. Hydrophilicity test results.

	Water flow test		Drop test		Sinking test	
Sample no.	Value (g)	Degree	Value (s)	Degree	Value (s)	Degree
1	1.31	3	39.70	3	110.30	3
2	0.81	3	22.60	3	106.00	3
3	1.05	3	8.90	3	143.00	3
4	0.58	3	29.30	3	143.70	3
5	1.17	3	48.00	3	103.30	3
6	1.21	3	14.30	3	41.30	1
7	0.87	3	21.20	3	64.00	2
8	1.11	3	14.30	3	51.00	2
9	1.03	3	20.50	3	60.00	2
10	6.24	1	2.50	1	14.30	1
11	5.36	1	5.00	2	14.00	1
12	5.17	1	4.90	2	18.00	1
13	0.46	3	42.80	3	116.00	3
14	1.52	3	6.90	3	21.70	1
15	1.03	3	34.50	3	140.70	3
16	1.33	3	16.70	3	53.30	2
17	1.03	3	30.10	3	75.00	2
18	1.24	3	26.10	3	110.00	3
19	0.81	3	38.10	3	136.30	3
20	5.05	1	4.00	2	20.00	1
21	1.56	3	12.50	3	44.70	1
22	9.18	1	2.20	1	18.00	1
23	0.99	3	43.60	3	102.30	3
24	0.64	3	32.70	3	50.70	2
25	5.53	1	2.40	1	25.30	1
26	0.54	3	27.70	3	43.00	1
27	1.23	3	42.60	3	62.30	2
28	0.38	3	30.40	3	110.30	3
29	1.32	3	40.20	3	34.30	1
30	0.19	3	64.80	3	142.00	3

case could be attributed to the similar principles upon which test methods are based (different amounts of water flow on fabrics from burette in two test methods).

Statistical analysis

Within the scope of the study, statistical analyses were carried out in SPSS package software to compare the results of the three different hydrophilicity test methods and determine the type and degree of effects of the selected parameters on hydrophilicity results.

Comparison of test methods

Correlation analysis was performed using the hydrophilicity degrees (1–3) in Table 3 in order to determine whether there is a linear relation between test methods investigating water absorption capacity of terry fabrics and to determine severity and direction of relation if there is such a relation. The reason for using hydrophilicity degrees instead of hydrophilicity values is that there are different intervals for values defined as "high", "moderate", and "low" in each test method. In order to eliminate the difference between the test methods, water absorption values were transformed into hydrophilicity degrees and used in this analysis. The results of correlation analysis are given in Table 4.

Some chosen results of correlation analysis are summarized as follows:

(1) There was a correlation at 1% significance level between the three test methods (the presence of a highly significant relation among test methods).
(2) There was a highly significant and positive relation between water flow and drop test with 0.937 correlation coefficient; moderate and positive relations were detected between water flow and sinking tests with 0.591 correlation coefficient and between sinking and drop tests with 0.553 correlation coefficient (Kalaycı, 2006). Accordingly, the most significant linear relation was determined between water flow and drop tests. In this regard, water flow and

Table 4. The correlation analysis results among test methods.

		Flow	Drop	Sinking
Flow	Pearson correlation	1	0.937(**)	0.591(**)
	Sig. (2-tailed)		0.000	0.001
	N	30	30	30
Drop	Pearson correlation	0.937(**)	1	0.553(**)
	Sig. (2-tailed)	0.000		0.002
	N	30	30	30
Sinking	Pearson correlation	0.591(**)	0.553(**)	1
	Sig. (2-tailed)	0.001	0.002	
	N	30	30	30

**Correlation is significant at the 0.01 level (2-tailed).

drop test results (hydrophilicity degree) were relatively parallel to each other. In other words, drop and water flow tests applied on a sample would provide the same hydrophilicity result with 99% reliability, while it will not be possible to reach this level of reliability for other test methods.

In addition to correlation analysis performed to compare test methods, it was aimed to form equations to predict water absorption degrees obtained with a test method without performing it, by using the results of another chosen test method; and for this purpose, curve estimation analysis was carried out. Linear, quadratic, and cubic equations were established in binary groups for the test methods by this analysis, and the ones with the highest R^2 value (the coefficient of determination) were selected and are given in Table 5.

In statistics, R^2 value is the proportion of variability in a data-set that is accounted for by a statistical model. In addition to this, R^2 is a statistic that will give some information about the goodness of fit of a model. Higher R^2 value means that estimation results by equations will be closer to real value. For instance, if the hydrophilicity degree (absorption time) obtained by the sinking test is put in its place in Equation (1), the absorption time of the drop test could be estimated as "second" and estimation reliability would be quite good, thanks to the high R^2 coefficient.

Equations (1) and (3) in this table have high R^2 values, while Equations (2) and (4) have moderate coefficient of determination (R^2 values); Equations (5) and (6) have low R^2 values. It is not suggested to use Equations (5) and (6) for the prediction due to low R^2 degrees. In general, it is concluded that equations including water flow test results have low R^2 values, which is considered to be caused by the effect of position of piles on fabric surface on the hydrophilicity property of the fabric. This will be discussed in detail in the next section of the study.

Investigation of the relation among weight, pile height and test methods

In addition to the correlation between the test methods, the direction and size of effects of grammage and pile height on the results obtained with these methods were also tested by correlation analysis and the results are given in Table 6.

In this analysis, "hydrophilicity values" obtained with these tests were used as input data and the results are summarized below.

(1) Considering grammage, the relation between this parameter and water absorption was found

Table 5. Equations obtained for prediction (for test methods).

Dependent variable	Independent variable	Equations	R^2	Equation no.
Drop (D)	Sinking (S)	$D = 0.561 \times S - 0.002 \times S^2$	0.854	1
	Water flow (Wf)	$D = 36.878 \times Wf - 10.639 \times Wf^2 + 0.727 \times Wf^3$	0.664	2
Sinking (S)	Drop (D)	$S = 4.193 \times D - 0.038 \times D^2$	0.847	3
	Water flow (Wf)	$S = 107.605 \times Wf - 30.697 \times Wf^2 + 2.099 \times Wf^3$	0.679	4
Water flow (Wf)	Drop (D)	$Wf = 0.320 \times D - 0.013 \times D^2 + 1.2 \times 10^{-4} \times D^3$	0.249	5
	Sinking (S)	$Wf = 0.181 \times S - 0.003 \times S^2 + 1.41 \times 10^{-5} \times S^3$	0.467	6

Table 6. The correlation analysis results among test methods, weight and pile height.

		Weight	Pile height
Flow	Pearson correlation	0.395(*)	0.370(*)
	Sig. (2-tailed)	0.031	0.044
	N	30	30
Drop	Pearson correlation	−0.528(**)	−0.480(**)
	Sig. (2-tailed)	0.003	0.007
	N	30	30
Sinking	Pearson correlation	−0.474(**)	−0.329
	Sig. (2-tailed)	0.008	0.076
	N	30	30
Weight	Pearson correlation	1	0.618(**)
	Sig. (2-tailed)		0.000
	N	30	30
Pileheight	Pearson correlation	0.618(**)	1
	Sig. (2-tailed)	0.000	
	N	30	30

*Correlation is significant at the 0.05 level (2-tailed).**Correlation is significant at the 0.01 level (2-tailed).

at 99% significance level in drop and sinking tests and 95% significance level in water flow test. In addition, the greatest correlation coefficient ($r = -0.528$) was detected between drop test and weight; however, this linear relation was at moderate level and negative direction. The negative relation determined in drop and sinking tests indicates that hydrophilicity value decreases with increase in weight per m^2; in other words, water absorption capacity improves (there is an inverse relation between hydrophilicity degree and hydrophilicity value in these tests). And the positive relation determined in water flow test means that hydrophilicity value increases as weight per m^2 increases (hydrophilicity degree improves as the value obtained in water flow test increases). In conclusion, it can be stated that water absorption property (hydrophilicity degree) improves with increasing weight for the three test methods.

(2) In the investigation of the relation between pile height and test methods, the highest correlation was obtained with drop test results again, and this linear relation was found weak and in negative direction at 99% significance level. In addition, a positive and weak relation was detected between water flow test and pile height at 95% significance level. However, there was no linear and significant relation between sinking test and pile height. As a result, similar to the comments in weight, it can be stated that hydrophilicity degree improves with increasing pile height in drop and water flow tests.

As no linear and significant relation was detected between pile height, weight per m^2, and test methods in the correlation analysis, curve estimation analysis was used to investigate the presence of a non-linear relation. As a result of the analysis implemented with SPSS packet software, separate quadratic and cubic equations were formed between each method and weight and pile height, and the equations with the highest R^2 were selected and are given in Table 7.

As can be seen in the Table, Equations (7)–(10) have high R^2 values, and therefore quadratic equation was chosen for weight-drop test and weight-sinking test as well as pile height and sinking test, while cubic equation was chosen for pile height and drop test. In other words, hydrophilicity degree of a terry fabric with known weight per m^2 could be estimated from Equation (9) without performing the sinking test. In the present case, 78.6% of changes in dependent variable (sinking) can be explained by weight per m^2 variable included in the model.

However, quadratic Equations (11) and (12) investigating the relation between weight water flow test and pile height water flow test were found to have moderate coefficient of determination. In this case, it can be claimed that these parameters (pile height and grammage) do not have statistically significant effects on the results of the water flow test. As hydrophilicity

Table 7. Equations obtained for prediction (for physical properties).

Dependent variable	Independent variable	Equations	R^2	Equation no.
Drop (D)	Weight (W)	$D = 0.190 \times W - 2.4 \times 10^{-4} \times W^2$	0.777	7
	Pile height (PH)	$D = 29.769 \times PH - 5.315 \times PH^2 + 0.250 \times PH^3$	0.774	8
Sinking (S)	Weight (W)	$S = 0.508 \times W - 6.3 \times 10^{-4} \times W^2$	0.786	9
	Pile height (PH)	$S = 29.334 \times PH - 2.378 \times PH^2$	0.756	10
Water flow (Wf)	Weight (W)	$Wf = -0.004 \times W + 1.17 \times 10^{-5} \times W^2$	0.538	11
	Pile height (PH)	$Wf = -0.134 \times PH + 0.042 \times PH^2$	0.531	12

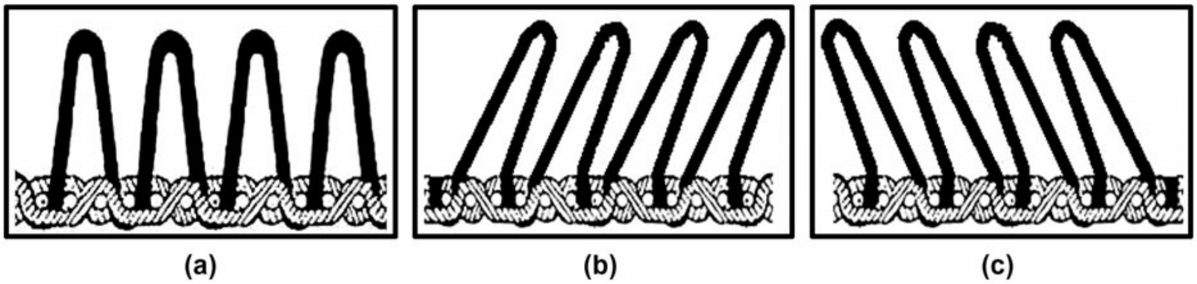

Figure 1. The possible positions of piles in technique.

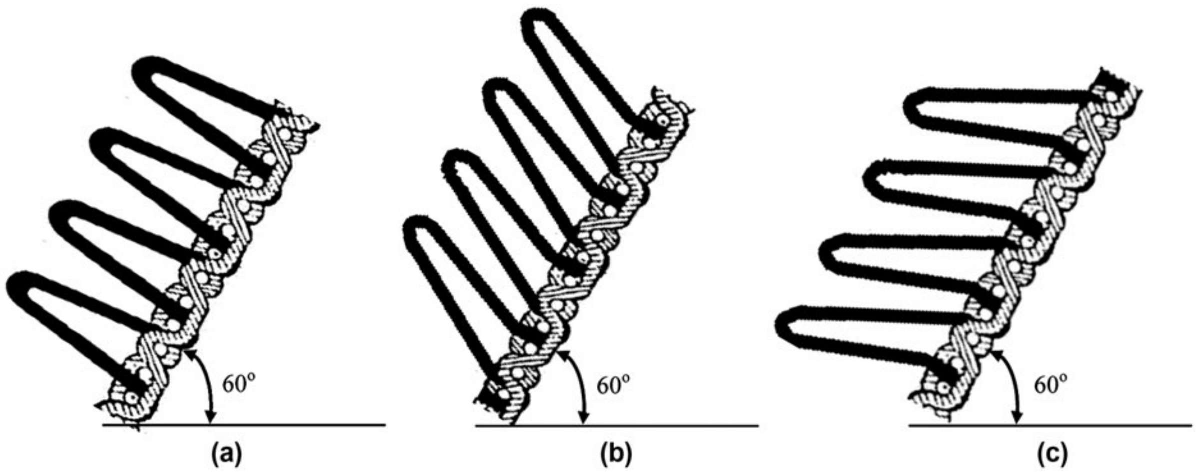

Figure 2. The schematic demonstration of towel placed on water flow test setup (for different pile positions).

degree is determined based on the water quantity absorbed during the water flow on a fabric placed at a constant slope in this test, the remaining duration of the water present on fabric directly affects the hydrophilicity degree, and this duration is considered to be related to the pile position on the fabric surface (Figure 1). The possible positions of piles in the technique are given in Figure 1 and the upright position of piles in Figure 1(a) is the expected/required position. However, due to external factors, piles tend to incline right and/or left as seen in Figure 1(b) and Figure 1(c), respectively.

The position of piles on terry fabric sample placed at 60° on test setup could obstruct or facilitate the flow of water sent at a certain flow rate. Figure 2(a) shows a sample with piles at upright position, and (b) and (c) show two different positions of a sample with leaning piles. In Figure 2(a) and (b), piles resist water downward and increase the water absorption by making it remain longer on the fabric. On the contrary, pile positions in Figure 2(c) are considered to facilitating water flow and shorten its contact time with fabric surface, and thus reduce water absorption amount (hydrophilicity).

In this case, hydrophilicity degree to be obtained in the water flow test is affected rather by pile position during the placement of sample in the setup than fabric construction. Therefore, in order to obtain reliable results, hand-combing application is suggested for helping the pile get into an upright position before the test.

Conclusion

Some selected results obtained with experiments and statistical analysis within the scope of the study are summarized below.

(1) In half of the terry fabric samples (50%) used in the study, hydrophilicity degrees obtained with the three test methods were similar; in addition to this, water flow and drop test results were same in 90% of samples, while water flow and sinking tests were similar in 60% of samples.
(2) Considering the statistical analysis of results, a correlation was detected between hydrophilicity degrees obtained with drop, sinking, and water

flow tests at 99% significance level, and the statistically most significant relation was determined between water flow and drop tests with 0.937 of correlation coefficient. It is considered that this situation is caused by the similarity between the principles of the test methods.

(3) It was determined that "hydrophilicity degree" improves with increasing grammage in the three test methods. This relation was found significant at 99% level for weight with drop and sinking tests and at 95% level in water flow test. The highest correlation coefficient was obtained between the drop test results and weight.

(4) In general, it can be said that hydrophilicity improves with increasing pile height according to drop and water flow tests. In addition, the highest correlation coefficient was detected between pile height and drop test, and there was no linear and significant relation between pile height and sinking test results.

(5) As a result of water flow test, it was concluded that hydrophilicity degree is affected rather by pile position during the placement of fabric sample in setup than fabric construction.

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