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An Experimental Approach on the Performance of Towels Part II. Degree of Hydrophilicity and Dimensional Variation

Abstract

In this experimental study, the relationship between the towel performance (hydrophilicity and dimensional variation properties) and selected physical & production parameters such as pile height, aerial density, type of softener etc. was obtained. For this purpose, the degrees of hydrophilicity and dimensional variation after washing the selected towel samples were tested according to the relevant standards, and the results obtained were analysed.

Key words: performance of towels, hydrophilicity, dimensional variation.

■ Introduction

Considering their end uses, towels should display certain properties such as appropriate hydrophilicity, softness, and dimensional variation (d_V), of which hydrophilicity is the most important quality parameter. Since towels are frequently washed for hygiene, dimensional variation after washing is also an important property. General descriptive information about their properties and performance has been given in detail in Part I of our publication [1]. In this article, only hydrophilicity degree (H_D), and dimensional variation are outlined.

The parameters affecting humidity absorption have been theoretically investigated by Anis [2]. In this study, a model was developed giving optimum absorption value for evaluated towels. It was seen that the pile height (H_P) value could not be higher than a definite value beyond which the loop cannot bear (resist) its weight.

Bozgeyik has experimentally investigated the effect of different parameters on the hydrophilicity degree and dimensional variation of a handling towel [3]. The results showed that while hydrophilicity degree was not affected by the number of thread and the aerial density (d_A) of the towels, the water absorption (W_A) increased with the increase in aerial density, and high pile.

The parameters affecting the properties in use such as dimensional variation and the friction fastness of towels have also been investigated by Funder et al. [4]. They suggested certain correlations between physical properties and properties during daily use.

The effects of repeated application of laundry softeners on fabric properties were studied experimentally by Anon [5]. Various terry towels were treated through ten laundering cycles, and next the towel properties were evaluated. The investigation carried out by Cary & Sproles compared five methods for measuring the moisture absorbency of terry towels [6]. The results indicated that the porous plate and sliding block methods might potentially be used for measuring the moisture absorbency of towels. Swani et al. [7] have compared the performance properties of terry towels made from open-end and ring-spun yarns. They stated that there was no difference in the water absorption rate, but the maximum absorption for OE towels was found to be better than that of ring-spun towels at a lower fabric density, as well as for a comparable fabric aerial density. Wasiak & Snycerski's investigation concerned the influence of the type of raw materials, the fabrics' structure, and the water absorption ability and handle of terry woven fabrics [8]. Nostadt & Zyschka [9] have evaluated the effect of softeners on the softness and hydrophilicity properties of towels, and explained that hydrophilic softeners are the most convenient for use.

Further studies have been carried out by Koç and Zervent taking into account the effects of physical, production, and performance properties on the defined performance of selected towel samples experimentally, and the results have been discussed [10, 11]. Zervent experimentally investigated the relationship between physical properties, selected production parameters, and the performance of towels [12]. The results obtained showed that the softness of towels decreased with the increase in aerial density and pile height,

although the aerial density and hydrophilicity degree of the towels could not be related to each other systematically.

In this paper, the results of the experimental study performed for determining the parameters affecting the hydrophilicity degree and dimensional variation in towels are presented. These parameters are considered as physical properties. The pile height, and dimensional variation of the towels have been measured on selected towel samples, and the results obtained were evaluated.

■ Experimental procedures

As explained in the first part of this investigation [1], the towel performance has been examined by applying Turkish standards. Here the standards concerning hydrophilicity degree and percentage of dimensional variation of towel samples are briefly described, and the corresponding procedures given below.

Determining the degree of hydrophilicity

In order to determine the hydrophilicity degree of samples, one of the methods known as the 'sinking Test' was adapted to the experiment as described in TS 866, which is called 'Determination of absorbency of bleached cotton textile materials' [13]. According to the sinking test, the prepared towel samples are put in a pot full of water and the sinking time (t_s) of a sample is measured. This procedure is repeated three times with different samples for one towel, and the arithmetical mean of the results is taken. The mean sinking time identifies the hydrophilicity degree of samples measured in seconds. For any towel, the smaller the value of sinking time which is found, the

higher the hydrophilicity degree of the corresponding towel will be. In other words, the sinking time for any towel should be as small as possible to give a higher hydrophilicity degree. According to the Turkish Standard TS 629 ('Terry towels and terry toweling'), when the hydrophilicity degree or sinking time is less than fifty seconds, the towel is called a hydrophilic towel.

Since the sinking test is known to be the most convenient method for towels, this method was applied to determine the hydrophilicity degree of samples in this study. In addition to this method, the determination of hydrophilicity degree can also be performed with the 'drop test' and the 'potassium chromate test'.

According to TS 866, in the drop test, the prepared towel samples 20×20 cm in size are put on a hoop. Next, a distilled water drop is dripped onto the sample with a burette, and the absorption time of the drop of water is measured. This procedure is repeated ten times, and the arithmetical mean of these measured values is taken. The smaller the dropping time, the higher the hydrophilicity degree of corresponding towel will be.

Another method used to determine the softness degree is the 'potassium chromate test' which is based on DIN 54924. In this method, five samples 3×25 cm in size in both warp and weft directions are prepared. Each sample is dipped into potassium chromate solutions from the tip of the sample, and the rising level of solution is measured consequently at 10, 30, 60, and 300 seconds. The arithmetical means of the 20 rising level measurements are taken in both warp and weft directions separately, and the results of these two values are examined. In general application, these two values are very similar to each other. Changing the towel type may give different values than that of the previous ones. To call a towel more hydrophilic, the measured value of the rising level of potassium chromate solution for that towel should be higher than those of the towel compared.

Determining dimensional variation

The dimensional variation of towel samples after washing is found by considering TS 392 which is known as 'determination of dimensional change after washing' [15]. According to this method, three different lines of 50 cm length are

marked in weft and warp directions on the surface of a sample towel of a given size. The numbers of marked lines are three in each direction, or six in total for one sample. The sample prepared in this way is washed in a standard washing machine under certain conditions. After washing, the sample is dried and the line displacements measured. Then either the geometrical variation of related lines detected are calculated separately as a percentage and the the arithmetical mean of corresponding three values mentioned above is taken; or the dimensional variation after washing can be determined directly by using a standard ruler known as a Sanfor ruler. These measurements have been repeated for both weft and warp directions. Like the other performance parameters, the value of dimensional variation of a sample should be as small as possible.

In addition to this method, the dimensional variation can also be determined in accordance with ISO 5077 'Textiles: Determination of dimensional change in washing and drying' [16]. According to this standard, wherein the original length and width of the samples were measured, the samples are washed and dried according to one of the procedures specified in ISO 6330. After washing and drying, the dimensions are measured, and consequently the dimensional change is calculated.

Materials used in experiments

22 selected pieces of towels were tested according to the relevant standards, and these values obtained with their units are given in Table 1. It can be seen that the aerial density of the samples under investigation range from 390 to 550 g/m², the ground warp yarn linear densities of the samples varied between 23-29 tex, and the pile height ranges from 4.4 to 7.5. The pile height is the most important physical property considered in the present study, and this property is referred to as the 'degree of terry ratio of the loop warp' in a non-dimensional form. According to TS 629, the degrees of terry ratio of the loop warp were determined for each sample by following the procedure explained in detail in Part I of this study. In the present investigation, this ratio has also been defined as pile height [14].

In order to investigate the influence of different production parameters on the hydrophilicity degree and dimensional variation of a towel, the most effective or dominant type of parameters such as coloration process, type of softener, and the structure of the towel were examined, and the data concerning these values were obtained from the producers. The corresponding production parameters of the towel samples are illustrated by their sample numbers in Table 2. 13 towel samples were dyed in fabric form, 5 samples used dyed yarns in weaving, in

Table 1. Physical properties of samples determined experimentally.

| Sample number | Hp, - | Density, yarn/cm | | d _A , g/m ² | Yarn number, tex | | |
|---------------|-------|------------------|------|-----------------------------------|------------------|--------|------|
| | | Weft | Warp | | Weft | Ground | Pile |
| 1 | 5.6 | 17 | 27 | 413.7 | 34 | 28x2 | 27 |
| 2 | 4.8 | 19 | 27 | 462.8 | 33 | 23x2 | 32 |
| 3 | 7.1 | 20 | 25 | 435.6 | 33 | 24x2 | 27 |
| 4 | 5.5 | 19 | 27 | 526.9 | 36 | 23x2 | 24x2 |
| 5 | 4.8 | 21 | 29 | 519.7 | 34 | 28x2 | 28x2 |
| 6 | 6.4 | 17 | 24 | 420.6 | 28 | 28x2 | 34 |
| 7 | 6.4 | 16 | 27 | 500.0 | 49 | 29x2 | 35 |
| 8 | 7.4 | 18 | 27 | 550.0 | 47 | 28x2 | 36 |
| 9 | 4.4 | 18 | 27 | 448.0 | 34 | 28x2 | 34 |
| 10 | 4.4 | 16 | 27 | 412.0 | 36 | 29x2 | 34 |
| 11 | 6.3 | 19 | 26 | 402.0 | 35 | 27x2 | 27 |
| 12 | 6.4 | 22 | 27 | 476.3 | 33 | 23x2 | 26x2 |
| 13 | 6.6 | 20 | 26 | 401.0 | 34 | 27x2 | 35 |
| 14 | 5.9 | 20 | 24 | 443.3 | 35 | 24x2 | 24x2 |
| 15 | 6.2 | 18 | 25 | 465.0 | 35 | 24x2 | 35 |
| 16 | 7.5 | 19 | 23 | 511.2 | 35 | 23x2 | 34 |
| 17 | 6.1 | 18 | 23 | 503.2 | 35 | 23x2 | 24x2 |
| 18 | 6.1 | 18 | 28 | 438.4 | 36 | 24x2 | 34 |
| 19 | 5.2 | 16 | 26 | 512.4 | 35 | 23x2 | 28x2 |
| 20 | 5.8 | 18 | 25 | 508.6 | 33 | 23x2 | 23x2 |
| 21 | 5.1 | 15 | 27 | 390.0 | 35 | 28x2 | 33 |
| 22 | 6.0 | 19 | 28 | 396.2 | 35 | 27x2 | 28 |

3 samples optical bleaching operations were applied as finishing, and one sample was processed by printing (No 22). In addition to these, 2 samples were processed with cationic softeners (No 11, and 16), and the rest with silicone softeners.

Experimental results and discussion

In this experimental study to analyse the effect of aerial density, pile height and different production parameters on the hydrophilicity degree and dimensional variation values of the samples, the hydrophilicity degree and percentage dimensional variation of selected samples were determined by applying the procedures explained above, and we discuss the more important of the results which we obtained.

Parameters affecting the degree of hydrophilicity

In order to determine the influence of the pile height and aerial density values on the hydrophilicity degree, the sinking time of all samples were measured before the washing process. The sinking time of the towel represents the hydrophilicity degree of the corresponding sample. When these measurements were evaluated, it was seen that sample 3 has the highest hydrophilicity degree with 2 seconds, and the sample 22 has the least hydrophilicity degree. Sample 3 was produced with the fabric-form dyeing method, whereas sample 22 was coloured in a printing process; both of these samples were processed as un-cut pile form with silicone softener.

The variation between the hydrophilicity degree of examined samples and the pile height is shown in Figure 1.

Table 2. Selected production parameters of sample towels; F - Fabric-form dyeing, Y - Yarn dyeing, O - Optical Bleach, P - Printing, S - Silicone, C - Cationic, N - Non-ionic, A - Anionic, U - Un-cut pile, V - Velvet.

| Sample number | Colouration process | Type of softener | Velvet or un-cut pile towel |
|---------------|---------------------|------------------|-----------------------------|
| 1-10 | F | S | U |
| 11 | F | C | U |
| 12, 13 | F | S | V |
| 14 | Y | S | V |
| 15, 17, 18 | Y | S | U |
| 16 | Y | C | U |
| 19 - 21 | O | S | U |
| 22 | P | S | U |

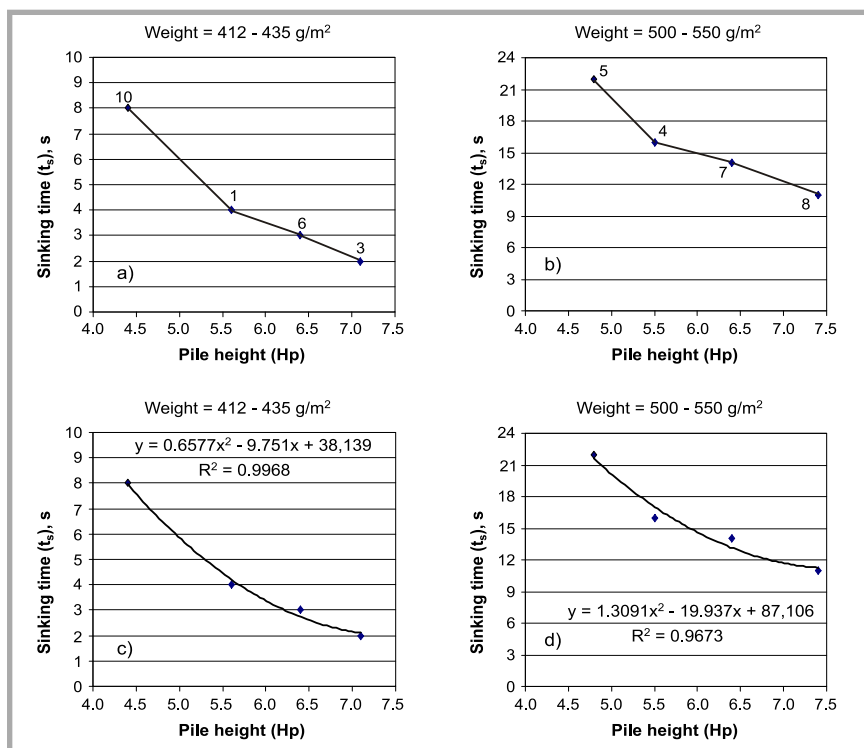


Figure 1. The sinking time/pile height variation of reference samples.

Table 3. Measured and predicted bending resistances of selected reference samples.

| Sample No | Pile height | Sinking time, s | | Sample No | Pile height | Sinking time, s | |
|-----------|-------------|-----------------|-----------|-----------|-------------|-----------------|-----------|
| | | measured | predicted | | | measured | predicted |
| 10 | 4.4 | 8 | 7.96 | 5 | 4.8 | 22 | 21.57 |
| 1 | 5.6 | 4 | 4.15 | 4 | 5.5 | 16 | 17.05 |
| 6 | 6.4 | 3 | 2.67 | 7 | 6.4 | 14 | 13.12 |
| 3 | 7.1 | 2 | 2.06 | 8 | 7.4 | 11 | 11.25 |

res 1 & 2. In these figures, the vertical distance corresponds to t_s in seconds, and the other axis represents the pile height of the samples; the different scales for the six curves should be noted. For a systematic analysis, the samples with the same physical properties (densities, yarn linear densities, etc.) have been grouped according to their aerial density intervals such as 412-435 g/m². In the figures, the samples with the almost same physical properties, apart from pile height, were selected, and the hydrophilicity degree (sinking time) against various pile height values were illustrated.

In each variation, the measured values are represented by solid lines, whereas the expected sinking time values correspondingly calculated with the use of the equations obtained are represented by dashed lines. In this evaluation, as in part I, the samples being produced by silicone softener, dyed in fabric form and having an un-cut pile type structure were defined as 'reference samples' and their properties were called 'reference proper-

ties'. The expected sinking time values of these samples have been accepted as almost the same as the measured values. The relationship between pile height and sinking time belonging to these reference samples can be seen in Figures 1a and 1b. The simple regression equations obtained and the relevant curves fitted are given in Figures 1c and 1d. These equations were used to predict the expected sinking time of a sample whose properties differ from the reference samples. It may be seen that the correlation coefficients (R^2) of these equations are considerably higher. In other words, the correlation between pile height and sinking time is strong. In these figures, y represents sinking time in seconds and x represents the pile height value. It can be seen from Figures 1a and 1b that, in general, increasing the pile height of the reference samples decreases t_s , which is interpreted as an increase in the hydrophilicity degree. So the larger the pile height found, the smaller is the sinking time value of the corresponding towel. The general trend obtained with these

reference samples was used to evaluate the behaviour of the other samples.

The predicted values calculated with these equations and the experimentally measured sinking time values of the samples considered in Figures 1a and 1b are given in Table 3 for comparison. It can be seen that there is a good agreement among the calculated and measured sinking time values.

In order to explore the effect of the various production parameters and physical properties selected on the sinking time of the towels, the variations given in Figure 2 were obtained. The sinking time values of some samples deviated from the general trend (i.e. samples 18, 22, 13, and 11). These deviations were attributed due to the samples having different properties than those of the reference samples. Due to the scale adopted in the figure, some of the measured values belonging to certain samples fell beyond the scale, and hence those values were not included in the figure.

In order to determine the real positions of the deviated points mentioned above, the prediction equations given in Figures 1c and 1d have been adopted. Therefore, if a sample had the same production parameters with the reference sample, it would take the experimental value coinciding with a point located on the dotted curve on the figures.

In Figure 2a, three samples with a aerial density within 412-438 g/m² were considered. Because samples 10, 6, and 3 have reference properties, the measured and predicted values of these samples coincided. However, the value of sample 18 deviated from the general trend described in Figure 1. While the measured sinking time of this sample is 7 seconds, the expected value is calculated as 3.9 seconds. This discrepancy would appear to be due to the coloration process of this sample; it is thus apparent from Table 2 that this sample was processed with dyed yarns, which causes the relatively high experimental value.

A considerable difference was seen between the predicted and measured sinking time in the case of sample 22 (Figure 2b), as this sample was produced by printing different from the reference samples. Experiments showed that this sample yielded 306 seconds sinking time and if this sample was produced in dyed fabric form, the corresponding sinking time would clearly be described as down to 3.5

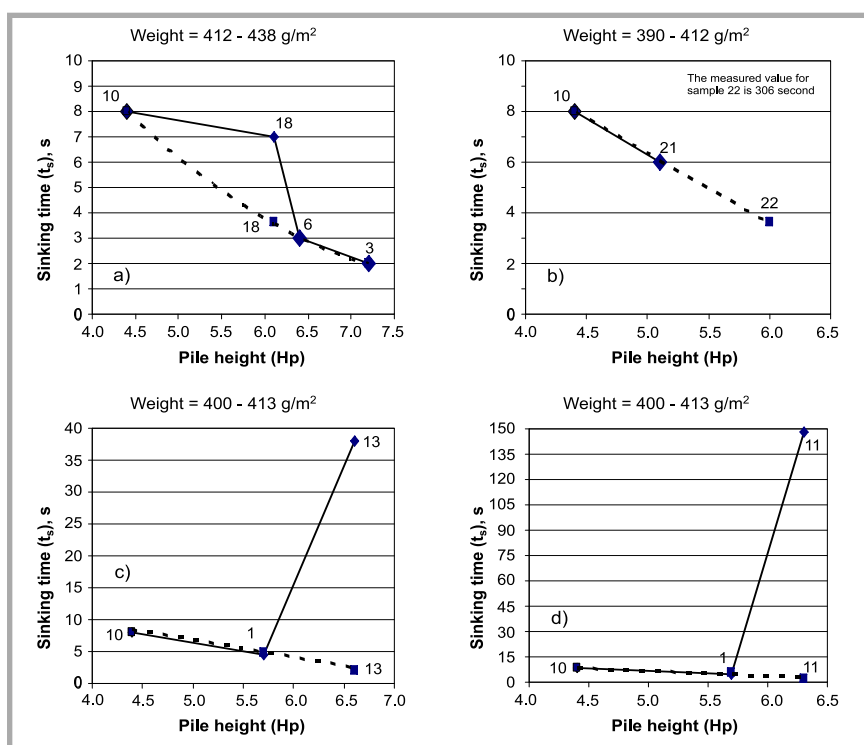


Figure 2. The variation of hydrophilicity degree with pile height.

seconds, which in turn increased the hydrophilicity degree as shown in the figure.

Similar behaviour in the case of sample 13 has been illustrated in Figure 2c. The higher experimental value obtained in this case may be explained as arising from the sample's structure. If this sample had a reference property (un-cut pile towel), the sinking time for this sample would be lower than that of the measured value.

Figure 2d demonstrates the results of three samples (10, 1, and 11), and there seemed to be a visible deviation in the results obtained for sample 11. The reason for this difference could be attributed to the production parameters of the sample, as sample 11 was processed with cationic softener. We can thus state that this feature of production leads to considerably high sinking time.

The effect of the washing process on hydrophilicity

In this study, the influence of the washing process on the hydrophilicity degree of the towel was also investigated. For this purpose, so as to determine the dimensional variation, the towel samples were washed by the following method described above, and the sinking time (hydrophilicity degree) of the washed samples were measured according to the TS 866 'sinking test'. The sinking time of selected

samples before and after washing are illustrated with the sample numbers in Table 4. It can be seen that considerable differences exist between the two values. The sinking times obtained for samples before washing are in general greater than those obtained after washing, which means that the washing process causes a higher hydrophilicity degree. For sample 22, the sinking time before and after washing have been recorded as 306 seconds and 7 seconds respectively. From this table, it can be stated that the

Table 4. The sinking time of before and after washing process.

| Sample number | Sinking time, s | |
|---------------|-----------------|---------------|
| | befor washing | after washing |
| 1 | 4 | 3 |
| 2 | 11 | 3 |
| 4 | 13 | 3 |
| 5 | 25 | 25 |
| 6 | 3 | 3 |
| 7 | 14 | 4 |
| 8 | 14 | 3 |
| 11 | 146 | 11 |
| 12 | 66 | 4 |
| 13 | 38 | 4 |
| 14 | 29 | 3 |
| 16 | 159 | 2 |
| 17 | 9 | 2 |
| 18 | 7 | 2 |
| 19 | 18 | 3 |
| 20 | 32 | 3 |
| 21 | 6 | 3 |
| 22 | 306 | 7 |

washing process is an important parameter in defining the sinking time or hydrophility degree of towels.

Parameters affecting dimensional variation

To determine the relationship between the dimensional variation and selected physical properties and production parameters of the samples, the towel samples were washed in accordance with TS 392 'determination of dimensional change after washing', and the percentage dimensional variation of all samples in both weft and warp side were measured. In general, the dimensional variation or size change of towel sample may be in the form of shrinkage or extension, and the acceptable limits are around 2% for weft and 4% for warp side. In addition to this, according to ASTM D5433-00, the acceptable limits of weft and warp side for towels are 5% and 10% respectively [17]. From the experiments carried out, it appears that all the samples under investigation seemed to shrink after the washing process. It was observed that the shrinkage values recorded for 3 samples occurred in the weft side were found to be over the limits described above.

Effect of the pile highness on dimensional variation

The variation of dimensional change with the pile height of towels for different aerial density, as well as the shrinkage values of both weft and warp side of selected towels, are demonstrated in Figure 3. Here, each curve corresponds to the variations obtained with the samples with the same physical properties apart from pile height. As in the evaluation of hydrophility degree, here some samples have also been defined as 'reference samples'. It can be seen that increasing the pile height increases the percentage of dimensional variation. In addition to this, in all samples apart from the velvet towels, the measured dimensional change in the warp side seemed to be higher than that in the weft side. The general trend explained above can easily be seen from Figure 3a on which samples 2 and 3 are evaluated.

Figure 3b demonstrates the results for three samples of aerial density within 390-415 g/m². Samples 21 and 1 were processed by silicone softener, whereas sample 11 was treated with a cationic softener. The dimensional change which occurred in sample 11 was higher than

that expected. This seems to be due to the softener used in the production of this sample. From the figures, the shrinkage value belonging to sample 21 in the weft side can be extracted as 1.5% and in the warp side as 3%, whereas sample 11 gives 4% in the weft side and 5.5% in the warp side.

Figure 3 (c) demonstrates the dimensional variation vs. pile height for three samples in a selected aerial density interval. The slope of the lines in the region marked as II seems to be steeper than that of region I. This increase is thought to be due to sample 17, which is obtained by dyeing yarns as the coloration process.

Effect of the aerial density on the dimensional variation

Figure 4 demonstrates the relationship between the aerial density and dimensional variation of the selected samples for both warp and weft sides. It can be

seen that, in general, the increase in aerial density decreases the dimensional variation in percent. In addition to this, the dimensional variation in warp side of all samples apart from the velvet towels were found to be higher than that of the other side.

The general trend can easily be seen in Figure 4a, and the samples considered in this figure have reference properties. In Figure 4b, two velvet towels with an pile height within 6.4-6.6 were evaluated, and it was determined that the dimensional variation recorded in the weft side gave relatively higher values than that of the warp side, in contrast with un-cut pile towels. This discrepancy would appear to be due to the type of structure of these samples.

The variation of three samples with an pile height within 5.5-6.0 was considered in Figure 4c. The dimensional variation values measured in both the weft and warp sides of sample 14 are found to

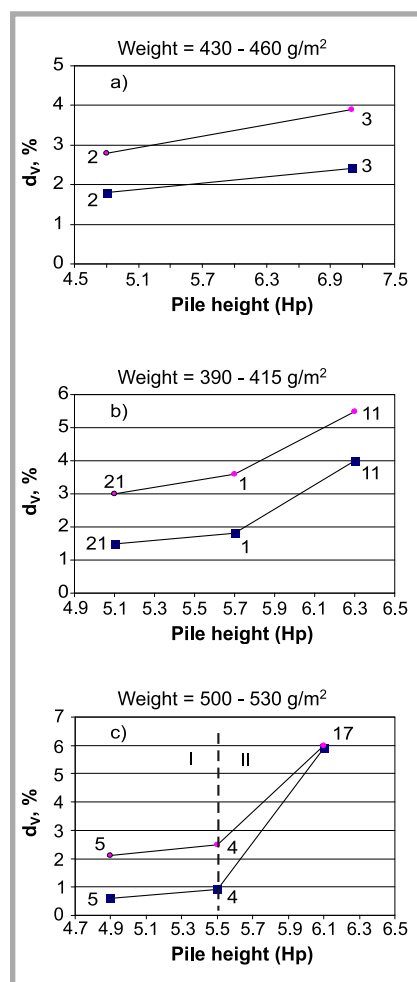


Figure 3. The dimensional variation versus pile height; ● - shrinkage in warp side, ■ - shrinkage in weft side.

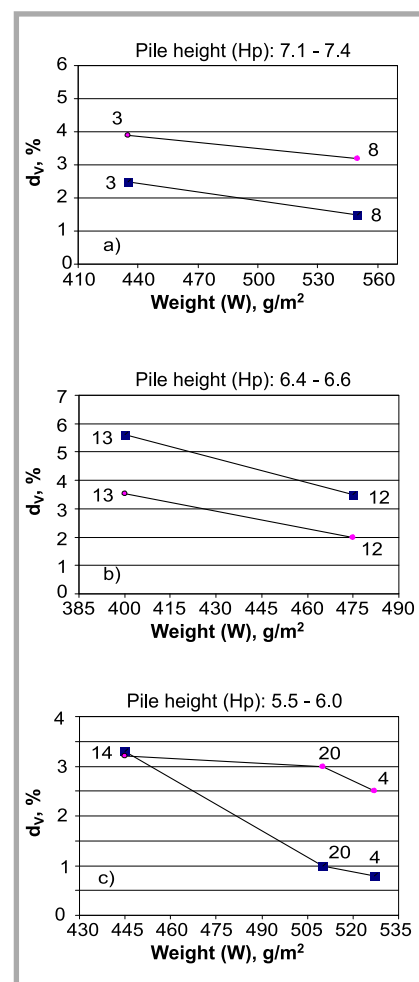


Figure 4. The dimensional variation vs. aerial density; ● - shrinkage in warp side, ■ - shrinkage in weft side.

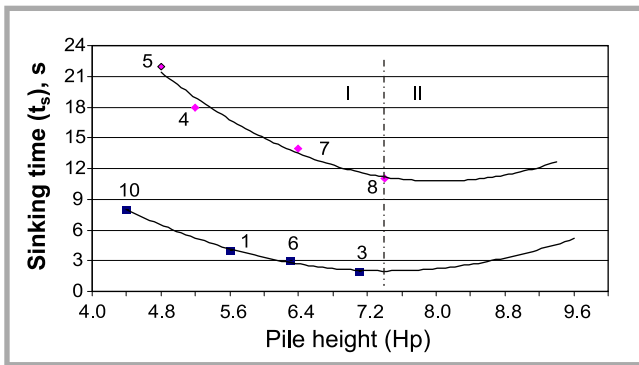


Figure 5. The variations of sinking time with pile height; \blacklozenge - 500-550 g/m², \blacksquare - 412-435 g/m².

be close to each other, whereas those of the other samples are considerably different. This difference is thought to be because sample 14 was obtained as a velvet form.

General evaluation

In order to examine the relationship between the pile height, aerial density and sinking time values of some of the reference samples more clearly, the variations demonstrated in Figure 5 have been re-introduced. This figure illustrates the regression curves as well as the fitted experimental data. Here, region I of the pile height within 4-7.4 corresponds to the measured sinking time values, whereas region II demonstrates the extended portion of the behaviour predicted by using the regression equations. As can be seen from region I, increasing pile height up to a certain value (7.4), increases the surface being contacted with water and hence decreases the sinking time for both aerial density intervals. After this certain value, sinking time starts to increase slightly (region II), meaning that

at these relatively higher pile height values, the loops tend to be bent with their aerial density and consequently cover the surface of the fabric, which in turn restricts the water absorption [2]. From this figure, it is also easy to predict the sinking time values for any pile height and aerial density intervals. In addition to this, the variations exhibited in Figures 1 & 5 can be used as a model to predict the behaviour of any towel in terms of sinking time.

Examining the variations illustrated in Figure 2, the production parameters have been found to have dominant effects on the sinking time values. As seen in Figure 2 (b), the printing process naturally decreases the hydrophilicity degree of the towels due to creating a film layer on the surface of the fabric examined. On the other hand, the cationic softeners have been found to be inconvenient for towels, owing to the corresponding chemical structure (sample 11, Figure 2d). The sinking time value of sample 13 in Figure 3 (c) was found to be better

than that of the uncut pile towels; this is attributed to the twist loss of the pile warp being opened after cutting process, and hence causing a decrease in water absorption.

Since in this type of fabric, the piles are produced on the warp side, the hydrophilicity degree and hence the dimensional variation on this side were found to be higher than that of the weft side (Figures 3 & 4). However, as can be seen from Figure 4b, the dimensional changes in the weft side of the velvet towels were found to be higher than that of the other side, due to the structural properties of velvet, i.e. as a cutting pile.

Table 6. The results of statistical analysis for the washing process; * - $F_{0.05, 1, 20} = 4.35$, ** - $t_{0.95, 10} = 1.81$.

| Process | Sinking time | |
|------------------------|--------------|---------------|
| | F value | t value |
| Washing process | 7.20 > 4.35* | 2.92 > 1.81** |
| Statistical evaluation | significant | significant |

Statistical analysis

The experimental results have been statistically evaluated by using Design Expert Analysis of Variance (ANOVA) software with F values of the significance level of $\alpha=0.05$, with the intention of finding out whether there was any statistically significant difference between the variations obtained. The results of the analysis of variance are given in Table 5. It may be seen that there was a statistically significant difference for the sinking time of samples tested in terms of pile height and aerial density. In other words, the table shows that pile height, and aerial density have significant effects on the towel's hydrophilicity degree. On the other hand, the differences in the dimensional variation of both sides of samples with a certain pile height were determined as insignificant. In addition to this, it was seen that there was a significant difference between the dimensional variation values for different aerial density values.

Table 5. Statistical analysis of variance results for hydrophilicity and dimensional variation; * - $F_{0.05, 3, 3} = 9.28$, $F_{0.05, 1, 3} = 10.1$, ** - $F_{0.05, 1, 4} = 7.71$.

| Parameter | Sinking time (hydrophilicity degree) | | Dimensional variation | | | |
|------------------------|--------------------------------------|----------------|-----------------------|----------------|-----------------|----------------|
| | F value | % contribution | Weft side | | Warp side | |
| | | | F value | % contribution | F value | % contribution |
| Pile height | 12.15 > 9.28* | 22.57 | 0.016 < 7.71** | 17.11 | 0.82 < 7.71** | 3.85 |
| Statistical evaluation | significant | | not significant | | not significant | |
| Weight | 122.08 > 10.1* | 75.57 | 14.8 > 7.71** | 78.61 | 10 > 7.71** | 71.79 |
| Statistical evaluation | significant | | significant | | significant | |
| Pile height x weight | - | 1.86 | - | 4.28 | - | 24.36 |

Table 7. The results of the t-student test; * - $t_{0.95, 6} = 2.447$, ** - $t_{0.95, 4} = 2.776$.

| Parameter | Sinking time (hydrophilicity degree) | Dimensional variation | |
|------------------------|--------------------------------------|-----------------------|----------------|
| | | Weft side | Warp side |
| Weight | 2.94 > 2.447* | 3.95 > 2.776** | 3.00 > 2.776** |
| Statistical evaluation | significant | significant | significant |

The data has also been evaluated to cover the relative importance of each source of variation in the ANOVA. The results obtained in this way are also given in Table 5. The effect of pile height accounted for 22.57% of total variation in t_s , whereas the aerial density was a major factor

contributing to 75.57% of total variation. The percent contribution values of aerial density for dimensional variation of the weft and warp sides were determined as 78.61% and 71.79% respectively.

In order to determine the influence of washing process on the hydrophilicity degree of towels, a statistical analysis was also applied. In Table 6, a statistically significant difference between sinking time after and before washing was determined according to variance analysis and the t-test. Hence, it was inferred that the influence of the washing process on hydrophilicity degree was primarily important.

In addition to variance analysis, the t-Student test has also been applied, and the sinking time and dimensional variation values of the weft and warp sides of the reference samples have been evaluated at two different aerial density intervals. As seen from Table 7, a significant difference was determined in this case for the significance level of $\alpha=0.05$.

Conclusions

With the experimental study carried out for investigating the performance of towels with special reference to the effects of hydrophilicity degree and dimensional variation, the conclusions drawn are outlined below.

1. It was shown that the hydrophilicity degree and dimensional variation values of the towels after washing had primary importance for the towels. The physical properties and the production parameters of the samples used in the experiments have also been found to be the most effective parameters in determining the performance of the towels, i.e. pile height, aerial density, softeners and the coloration process.
2. The experiments showed that the type of softener affects hydrophilicity degree to a great degree. The highest hydrophilicity degree or the lowest sinking time was ensured with silicone softener, and the other softeners clearly decreased the hydrophilicity degree of towels.
3. Since a layer on the coloured surface of towel is formed during the printing process, the hydrophilicity degree of printed towels should have a low value. In addition to this, the sinking time of towels produced with dyed yarns was higher than that of the towels dyed in fabric form. The hydrophilicity degree of the uncut pile towels was found to be better than that of the velvet towels.
4. In general, increasing the pile height decreases sinking time, which is interpreted as increasing the hydrophilicity degree. However there must be a certain limit for the pile height value beyond which the hydrophilicity degree tends to be decreased. This limit depends on the yarn number, twist, type of raw material and density, and varies from towel to towel. Up to this limit, an increase in pile height is desired from the hydrophilicity degree point of view, although the undesirable case occurs with respect to softness degree, as the increase in pile height generally decreases the softness degree.
5. The washing process appeared to be an important parameter in defining sinking time or hydrophilicity degree in a towel, as the sinking time detected in washed towels became lower than that of the towels which did not undergo any washing process.
6. By using the results displayed in this paper, it is possible to predict the sinking time of any towel with aerial density and pile height values. In other words, the variations exhibited in Figure 5 can be used as a model to predict the behaviour of any towel in terms of sinking time.
7. From the experiments carried out, it has been seen that all the samples under investigation appeared to shrink after the washing process. In addition to this, in all samples apart from the velvet towels, the dimensional change in warp side was measured to be higher than the variation in the weft side and in general, increasing the pile height increases the percentage of dimensional variation, and increasing the aerial density decreases the dimensional variation of towels.
8. It may be seen from the results of the statistical analysis that there was a statistically significant difference for the sinking time values of the samples tested in terms of pile height and aerial density. On the other hand, the differences in the dimensional variation of both sides of samples with a certain pile height were determined as not being significant. It was also seen that there was a significant difference

between the dimensional variation values for different aerial density values. Lastly, a statistically significant difference between sinking time as measured before and after washing was determined according to both the variance analysis and the t-test.

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