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An Experimental Approach on the Performance of Towels – Part I. Bending Resistance or Softness Analysis

Abstract
This experimental study aims to investigate the performance of towels. In order to do this, we obtained the relationships between the towel's performance and selected characteristic properties such as pile highness, aerial density, type of softeners, and dyeing process. For this purpose, the selected towel samples were tested in accordance with the determination of degree of hydrophility, softness, and dimensional change after washing; then the results obtained were analysed. In this first part of our investigation, the effects of pile highness and aerial density on the bending resistance or the softness of towels have been discussed.

Key words: *performance of towels, softness degree, pile highness, area mass.*

Abbreviations used: *Hp – pile highness, RB – bending resistance, SD – softness degree, d_A – aerial density (mass per square metre).*

Introduction

Towels produced in different sizes are textile products which have important properties such as water absorption and softness, and they may be classified according to their sizes as hand-, face-, bath-towels, and Turkish bath towels. Apart from this classification, towels can also be divided into four major categories according to their d_A as light, middle, heavy, and very heavy towels [1].

The towels (woven or knitted fabrics) have almost similar physical properties apart from border, short pile distance, Hp & strength. In addition to this, they should also for end use have such properties as hydrophility, softness and dimensional variation, of which hydrophility is the most important parameter in towel quality. The degree of softness should be as high as possible, because of contact with skin during daily use; the dimensional variation of towels after washing should also be as low as possible. These characteristic parameters define the performance of towels and determine their quality. Other important parameters, the so-called production parameters which influence the performance of towels, are the actual structure (un-cut pile or velvet), type of softeners and the colouration process.

Swani et al. [2] have compared the performance properties of terry towels made from open-end and ring-spun yarns. They proved that there was no difference in their water absorption rate, but the maximum absorption for OE towels was found to be better than that of ring-spun towels at lower fabric density and for comparable d_A. Nostadt & Zyschka [3] have described the advantages and disadvantages of softeners, examining the effect of softeners on the hydrophility and softness of towels. The investigation carried out by Wasiak & Snycerski concerned the dependencies of water absorption ability and the handle of terry woven fabrics [4]. The aim of this study was to find out how the level of two usability features depends on the kind of raw materials, the woven fabric's structure and finish. Chen et al. [5] have evaluated the effect of softeners on the SD of fabrics by means of the Kawabata system and by fuzzy evaluation. The correlation between both evaluations was found to be strong for pure cotton fabric, but very weak for 50/50 cotton/polyester. Barndt et al. [6] investigated the effect of silicone finishes on the softness of denim fabrics and confirmed their good influence. Frydrych & Matusiak [7] developed a method for calculating the general handle factor (GHF) of a woven fabric. The tests carried out showed that woven fabrics with elastomeric finishing had the highest GHF value. Sabia & Pagliughi [8] evaluated silicone fabric softeners with the use of the Kawabata system (KGH), and indicated that the KES could distinguish differences between classes of silicone finishes and so provide a quantitative evaluation. Nishimatsu's investigation [9] concerned the application of factor analysis to the hand of terry fabrics. Zervent investigated the relationship experimentally between physical properties, selected production parameters and performance of towels [10]. Further studies on the performance investigation of the towels have been carried out by Koç and Zervent, taking into account the effects of physical, production and performance properties on the defined performance of the selected towel samples experimentally, and the results were discussed in [11, 12]. The parameters influencing the performance of towels have been investigated in order to determine the type and the characteristics of towels examined experimentally, and the results are presented here. These parameters were considered as physical properties (Hp, d_A, yarn number etc.) and production parameters (the kind of softeners, the type of colouration process etc.). Having established the physical properties and production parameters of the sample towels, a series of experimental works has been performed on the selected towel samples. These experiments consist of determining the hydrophility, the dimensional variation and the softness of towels under investigation.

The primary objective of the present investigation is to establish a definite relationship between the performance of towels, their physical properties and production parameters. The aimwas to develop an experimental model suitable for evaluating the basic production, physical and performance properties of towels used in different areas. This study forms a part of an extended examination on the performance of towels, including the effects of the different parameters; here only the RB or the SD results are evaluated, and the results discussed are given.

Experimental procedures

Some methods to be used in determining softness, dimensional change after washing and hydrophility degree have been standardised by the Turkish Standards Institute (TSE), and they have different codes attributed to the related standards, such as TS 866. In this experimental study, the basic procedure concerning the experiments is based on TS 1409, determining the degree of softness. A brief description of this procedure is given below.

Determining the SD

TS 1409 ('Stiffness Determination of Woven Textiles') has been taken as a primary test method to determine the SD of samples [13]. The test equipment suggested in this standard, which is referred to as 'Constant Angularity Test Equipment' [14, 15] was designed and built in our laboratory (Figure 1). This equipment consists of two parallel perspex plates and a thin solid stationary perspex plate fitted on top of these two plates horizontally. On the outer surface of each parallel perspex plate, an inclined line is drawn, making a 41.5º angle with the top of the corresponding plate; these lines are called index lines. A gap between the two parallel plates exists through which the free end of the sample bends easily. Four samples in the warp direction and four in the weft direction are prepared. The sample is situated horizontally on the solid plate, and with a metre rule on it, it is slid towards the gap. As soon as the sample reaches the corner of the angled line, the free end of the fabric will start to drop or try to be bent into the gap; the movement of the ruler is continued until the tip of the sample is in the same plane with the inclined lines; after that position, the moving action will be halted.

During this experiment, the length of the moving sample or the dropping length denoted as L, is recorded. The length L corresponds to a distance between the edge of the stationary plate and the zero point of the ruler. For each towel sample, two ends of two sides (the front and back of the sample) are tested. This means that for each sample, four tests should be performed. At the end, for each towel sample prepared, a total of 32 test runs are carried out, defined as above.

Arithmetical means of the 16 measured values of L in warp and weft directions were taken separately, and these arithmetical means of corresponding data have been denoted as L_1 and L_2 in the warp and weft direction respectively. Then, the bending lengths (and consequently the RB or bending rigidities of that sample in each direction) could be obtained in sequence by using these values as follows;

$$C_1 = \bar{L}_1/2,\ C_2 = \bar{L}_2/2 \qquad (1)$$

$$G_1 = 10\ W\ C_1^3,\ G_2 = 10\ W\ C_2^3 \qquad (2)$$

where W is the area mass of the sample in grams, C_1 is the bending length (warp direction) in cm, C_2 is the bending length (weft direction) in cm, G_1 is RB in warp direction and G_2 is RB in weft direction with the unit of mg·cm.

Having established the G_1 and G_2 values, the general RB marked G of the corresponding sample was evaluated by taking the geometrical mean.

This value represents the SD of a towel from which the samples are taken. According to this procedure, the greater the RB, the lower SD of the towel concerned was assigned. Hence, in general, it may be expected that the RB of a sample should be as small as possible; i.e. the SD should be expected to be as high as possible, which in turn improves the handle of the towel.

In addition to this method, the SD can also be measured by following the procedure given in ASTM D4032 [16]. In this standard, Stiffness Tester Equipment is described; it includes a vertical column with a pneumatic cylinder and gauge on it. This method is based on determining the magnitude of load exerted to pass the sample through a hole. In this equipment, there is a plunger ring plate with a hole in the centre, and a moveable vertical column pushing the sample through this plate with a certain load towards the sample allowing it to pass through the hole. During this process, the applied load is read directly from test equipment. This procedure is repeated three times with different samples for one towel, and the arithmetical mean of the measured load values is taken. It may be explained that the higher the mean load value which is obtained, the lower is the SD of the towel. A similar method is described in [17].

Materials used in experiments

22 pieces of 100% cotton woven towels from different producers have been used. In each sample, ground warp yarns are plied, whereas the weft yarns are single. Besides three towel samples, the rest of the samples have single pile warp yarns. The Hp, d_A, densities and yarn numbers have been established experimentally in this study, and are listed in Table 1. It can be seen that the Hp of the samples ranges from 3.8 to 7.4, and the warp densities of the samples varied between 24-29 yarn/cm. In addition to this, the area mass of the samples ranges from 358.8 to 586 gr/m^2. Hp is the most important property considered in this study, and is referred to as the degree of terry ratio of the loop warp in a non-dimensional form. According to TS 629, 10 pile warp yarns are taken out of samples of 5×10 cm size, and the total length of these straightened yarns (i.e. without crimp) is measured. This total value is divided by 100, and so the degree of terry ratio (defined as 'Hp') of the loop warp is noted for each sample [1, 4].

However, the production parameters (kind of softeners, type of colouration process, construction type, i.e. velvet or un-cut pile) of samples were taken from the producers concerned. Table 2 illustrates the related production parameters belonging to 22 towel samples under investigation.

It may be seen from this table that 3 samples (18, 19 and 20) were woven with yarn-dyed, one sample (21) was produced with the optical bleach method, one sample (22) was printed, and the remaining (17) towel samples were dyed; two samples were produced with the use of anionic softener, one sample with non-ionic softener, one sample was treated with cationic softener, and silicone softener was used for the others.

The colouration processes adopted on the samples for which the same method is applied have been found to be basically similar, although very small differences might be expected to exist. For instance, all the towels dyed in fabric form were coloured using reactive dyestuff by applying the exhaustion method. In addition to this, the softener treatment and optical bleaching process also showed a considerable similarity to a large extent.

Experimental results and discussion

Having determined the physical properties and production parameters, the SD

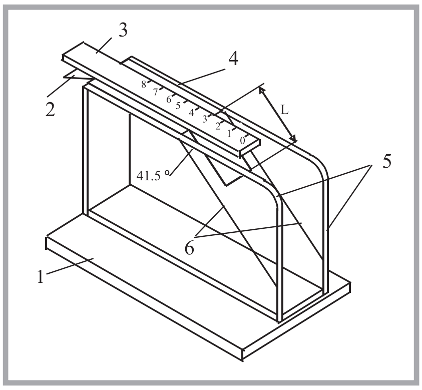

Figure 1. *Constant Angularity Test Equipment; 1 - base, 2 - sample, 3 - movable ruler (template), 4 - stationary plate, 5 - perspex plates, 6 - index lines.*

Table 1. Physical properties of samples determined experimentally.

Sample number	Hp, -	Density, yarn/cm		d_A, gr/m^2	Yarn number, tex		
		Weft	Warp		Weft	Ground	Pile
1	5.6	17	27	413.7	34	28x2	27
2	6.3	19	26	402.0	35	27x2	27
3	4.8	20	25	431.1	35	28x2	28
4	4.3	18	26	383.3	35	29x2	28
5	4.8	19	27	462.8	33	23x2	32
6	3.8	16	25	358.8	36	29x2	27
7	7.1	20	25	435.6	33	24x2	27
8	5.5	19	27	526.9	36	23x2	24x2
9	4.8	21	29	519.7	34	28x2	36
10	6.4	17	24	420.6	28	28x2	34
11	6.6	20	26	401.0	34	27x2	35
12	6.4	16	27	500.0	49	29x2	35
13	7.4	18	27	515.0	33	29x2	35
14	7.1	19	27	586.0	47	28x2	35
15	4.4	18	27	448.0	34	28x2	34
16	4.4	16	27	412.0	36	29x2	34
17	6.3	18	27	419.0	34	23x2	33
18	5.7	19	23	485.3	33	23x2	24x2
19	6.2	18	25	465.0	35	24x2	35
20	6.1	18	28	438.4	36	24x2	34
21	5.8	18	25	508.6	33	23x2	23x2
22	6.0	19	28	396.2	35	27x2	28

of all samples were measured by the procedure outlined above. In order to examine the type of parameters affecting the softness, a set of experiments have been carried out. Selected experimental results are discussed below.

Effect of pile highness on softness degree

To determine the influence of selected physical properties (Hp and area mass) on softness, firstly the RB values of all samples (22 pieces of towels) were measured. For this purpose, 32 values were measured for each sample, and hence a total of 704 tests were carried out for all of the samples considered in this study. These values showed that the maximum RB value was 401.66 mg·cm for sample number 14, and the minimum RB value was 120.07 mg·cm for sample number 6.

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-cutpile towel
1, 5, 7-10, 12-17	F	S	U
2	F	C	U
3	F	N	U
4, 6	F	A	U
11	F	S	V
18-20	Y	S	U
21	O	S	U
22	P	S	U

The existence of several different parameters identifying the towel samples makes investigation on this basis very difficult. For a systematic analysis, samples with the same physical properties, i.e. densities and yarn numbers, have been taken as a pair or put in different groups according to their selected properties. To examine the effect of Hp of samples on RB, the results corresponding to the samples having the same physical properties except the Hps were gathered at certain d_A intervals; typical findings are given in Figure 2 and 3. The figures give the experimental results recorded at different d_A intervals. The influence of Hp, H_p on RB of selected towels may easily be noticed from these figures. The vertical distance in each curve corresponds to the RB in mg·cm, and the different scales for six curves should be noted.

Some samples under investigation which were produced by silicone softener, dyed in fabric form and having an un-cut pile were defined as 'reference samples', and their properties were called 'reference properties'. The experimentally measured relationship between Hp and RB of these reference samples can be seen in Figure 2. Here, the reference samples have been selected among the samples given in Table 1 in such a way that the d_As of the samples fall in the ranges 412-435 gr/m^2 in Figure 2(a), and 500-526 gr/m^2 in Figure 2(b). It may be easily noticed that increasing the Hp (meaning different samples, i.e. sample no 1, 10, 7 or 12, 13) causes an increase in RB which corresponds to these samples almost linearly. These increases in RB can be interpreted as decreases in SD of the corresponding samples, which in turn lead to an unfavourable case.

Simple regression analysis gives a linear variation corresponding to the measured values as illustrated in Figure 2(c) and (d), where the variation obtained in Figure 2(c) corresponds to the values given in Figure 2(a). On the other hand, the regression line in Figure 2(d) belongs to the values given in Figure 2 (b). In these figures, we give the linear lines fitted to the data with their regression equations as well as the correlation coefficient. Here, Y represents RB in mg·cm and X represents Hp values. As can be seen, the calculated results were well suited to the corresponding actually measured values.

The general trend obtained with reference samples and the variations given in Figure 2 have been used as a basis to explain the general behaviour which can be obtained with other samples. In other words, this basic behaviour can be used for comparing towels with various production and physical parameters.

The predicted values calculated with these equations and the experimentally measured RB values of the samples considered in Figure 2(a) and (b) with their Hp were given in Table 3 for checking. Hence, the variations exhibited in Figure 2(c) and (d) can be used as a model to predict the behaviour of any towel in terms of RB.

In order to explore the effect of several production parameters and physical properties selected on the RB of the towels, the variations given in Figure 3 have been obtained. The figure contains the linear variation given in Figure 2 (dotted lines) along with the other variations obtained for different samples (solid lines). In other words, the RB values for certain towel samples deviated from the linear variation (i.e. the samples 2, 3, 11, 19 and 20). These deviations from the general trend (the trend obtained for the reference samples) were attributed to the samples with different properties than those of the reference samples.

In order to predict the real positions of the deviated points, a simple linear interpolation technique has been applied, expecting that these samples might have the properties matching the properties of reference samples. In other words, if a sample had the same production parameters as the reference sample, it would take the experimental value (RB) coincident with a point lying on the linear line (dotted line) on the figures.

Figure 3(a) demonstrates the results obtained for three samples (16, 1 and 2). It may be seen that the general trend of linear variation for three samples disappears in sample 2. This discrepancy appears to be due to the type of the softener used in manufacturing. Samples 16 and 1 are the reference samples described above. The measured value of RB related to sample 2 with an Hp of 6.3 is recorded as 175 mg·cm, whereas the expected value (obtained by following the procedure explained above) corresponding to the same Hp or the value for the same sample becomes 198 mg·cm. The reason that the actual (experimentally detected) value is less than the value expected could be attributed to using different softeners (cationic softener), whereas for the reference samples (16 and 1) silicone softener was used.

The effect of the Hp on the RB, and so on the SD of the towels considered, may be noted more clearly from Figure 3(b). In this figure, three samples with an area mass of 400-413 g/m^2 were considered. It may be clarified that the Hp varied from 4.4 to 6.6, and the configuration of the figure tended to be slightly different than that of Figure 3(a). Again there seemed to be a slight deviation in the results obtained for sample 11. The reason for this is again found to be due to the production parameters, since this sample was produced as velvet towel. If this sample had a reference property (un-cut pile towel), the RB value for this sample would be higher than that of the actual measured value. From the variation demonstrated in Figure 3(c), it may be observed that two samples (labelled 3 and 20) seemed to have different properties than the reference properties. In the figure, the points labelled 16, 10 and 7 represent the reference samples. Sample 3 was produced by non-ionic softener, and sample 20 was produced with dyed yarns differing from the other samples. Due to these factors, the experimental RB values for these samples gave relatively higher values than those of the reference samples. A similar detected variation can be seen in Figure 3(d). In this case, a considerable difference was determined between the expected and experimental RB values for sample 19, for which the experimental value is higher than it might be. This sample was produced with dyed yarns which differed from the reference samples. From these variations or recorded results, it may be inferred that an increase in Hp would mean an increase in RB, and therefore a decrease in the SD of the towels.

The effect of the area mass on the SD

Since the d_A of any woven fabrics with special reference to towels is an important physical property, the variation of RB with direct d_A in grams has also been examined. Due to the difficulties in investigating the RB, here again the figures have been tidied up according to the different Hp intervals. Figure 4 and 5 demonstrate the variation of RB with d_A in grams for different Hps, which are organized as six intervals. In the Figure 4, only the values belonging to the reference samples have been considered, in order to obtain a general trend which could then be taken as reference behaviour. It is clear from the figure that an increase in the d_A of the towels increases the RB as expected, meaning a decrease in SD; this linear trend is very similar to Hp effect discussed earlier.

Simple regression analysis has also been applied to this data, as before, and the results obtained were given in Figure 4 (c) and (d). Here again, in these equations, Y represents the RB in mg·cm and X represents d_A in g/m^2.

Like Table 3, the predicted and measured RB values of the samples illustrated in Figure 4 (a) and (b) were demonstrated together in Table 4.

In order to investigate the effect of several production parameters and d_A on the RB of the towels, the variations given in Figure 5 have been obtained. The variation for four samples (No. 3, 4, 5 and 16), which have an Hp ranging between 4.3-4.8, were considered in Figure 5(a). The experimental result obtained with sample number 4 was deviated, giving a considerably higher value than that expected, whereas only a slight deviation was observed on the values corresponding to sample 3, giving a slightly higher value than that of the reference value.

Figure 5 (b) demonstrates the variation of RB with d_A for three samples (11, 12 and 19). Since sample No. 12 is only the reference sample, in order to apply the same procedure explained before, another

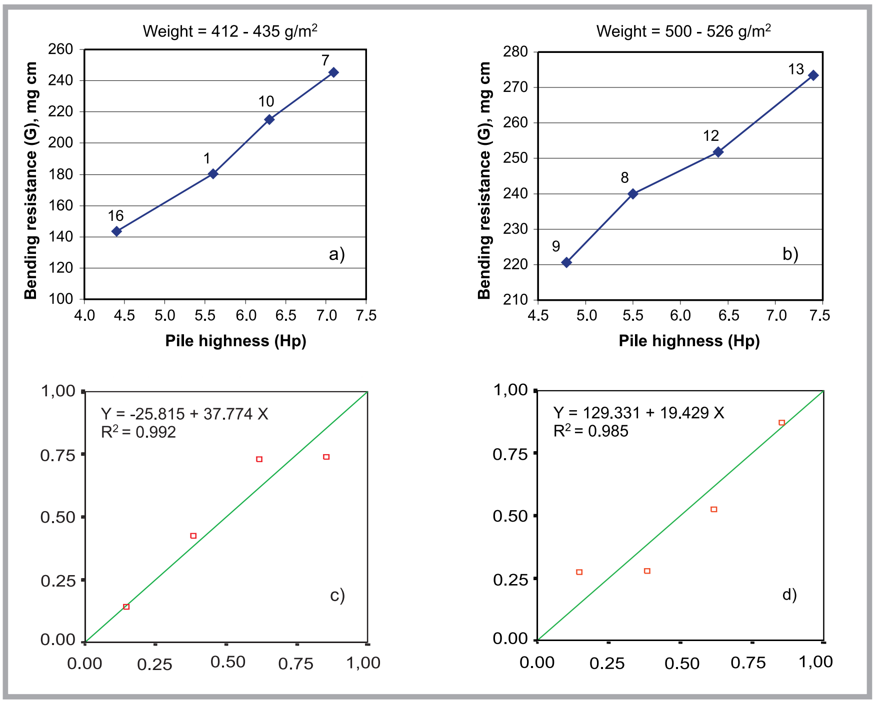

Figure 2. *RB vs. Hp of reference samples.*

Table 3. *Measured and predicted RBs of selected reference samples.*

Sample No	Hp	RB, mg·cm		Sample No	Hp	RB, mg·cm	
		Measured	Predicted			Measured	Predicted
16	4.4	143.53	140.39	9	4.8	220.57	222.59
1	5.6	180.50	185.71	8	5.5	240.00	236.19
10	6.4	215.00	215.93	12	6.4	251.70	253.67
7	7.1	245.39	242.38	13	7.4	273.30	273.10

reference sample is needed in this case. For this reason, the expected value of sample 11 was transferred directly from Figure 3 (b); using the expected values for sample 11 and 12, the expected RB for sample 19 was obtained as shown. It may be seen that there are slightly different values detected in the case of two samples (19 and 11). These discrepancies causing the deviation from the general trend might have occurred due to the production parameters (sample 19 was produced with dyed yarns, and the sample was manufactured as velvet towel).

The RB of sample number 18 was deviated, giving a considerably higher value than that expected (Figure 5(c)). This sample and sample 19 given in Figure 5(b) were produced by the same colouration method, and so these samples displayed the same behaviour. The experimentally obtained RB of samples 6 and 4 gave relatively higher values than those predicted in Figure 5 (d). These samples had the same production parameters and physical properties, excluding the d_A, but they were produced with anionic softener which differed from the reference samples.

Combined effects of Hp and d_A

In order to follow the effects of d_A and Hp on the RB, the variations illustrated in Figure 6 have been recorded. The first two figures show the variation of RB with d_A for different Hp (Figure 6 (a, b)), whereas Figure 6 (c) illustrates the RB variation with Hp for different d_A values. In the figures, the different samples with their labels are noted. As explained before, in general, increasing the d_A and Hp increases the RB. In Figure 6 (b), the d_A in grams varies from 410 to 470 gr/m^2, and it can easily be seen that for any towel with any d_A, the RB can be predicted for different Hp values (see the chain dotted line perpendicular to the horizontal axis, the line I-I). In Figure 6 (c) the Hp is changed from 4.2 to 6.6, whereas the d_A intervals corresponding to two lines are taken as 410-420 g/m^2 and 448-465 g/m^2 respectively. The same explanations mentioned before are also valid here. The prediction of a RB or a SD of any towel with a certain Hp and d_A may also be possible by following any perpendicular line similar to I-I.

General evaluation

In order to see the relationship between the Hp, d_A and RB of the selected reference samples more clearly, the variations illustrated in Figure 7 have been obtained. In obtaining this figure, the ref-

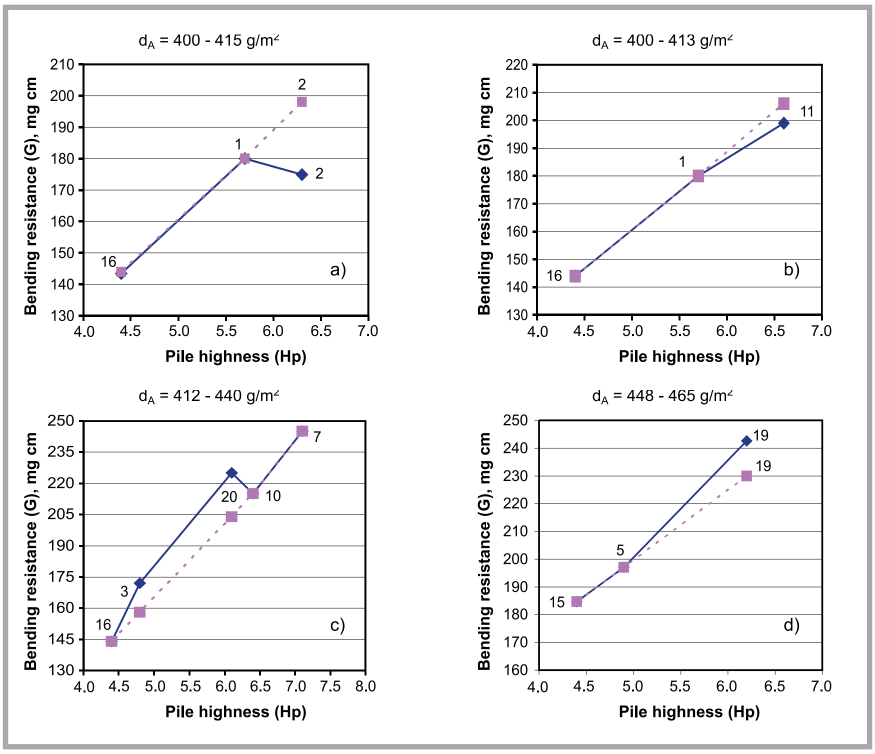

Figure 3. RB-Hp variation.

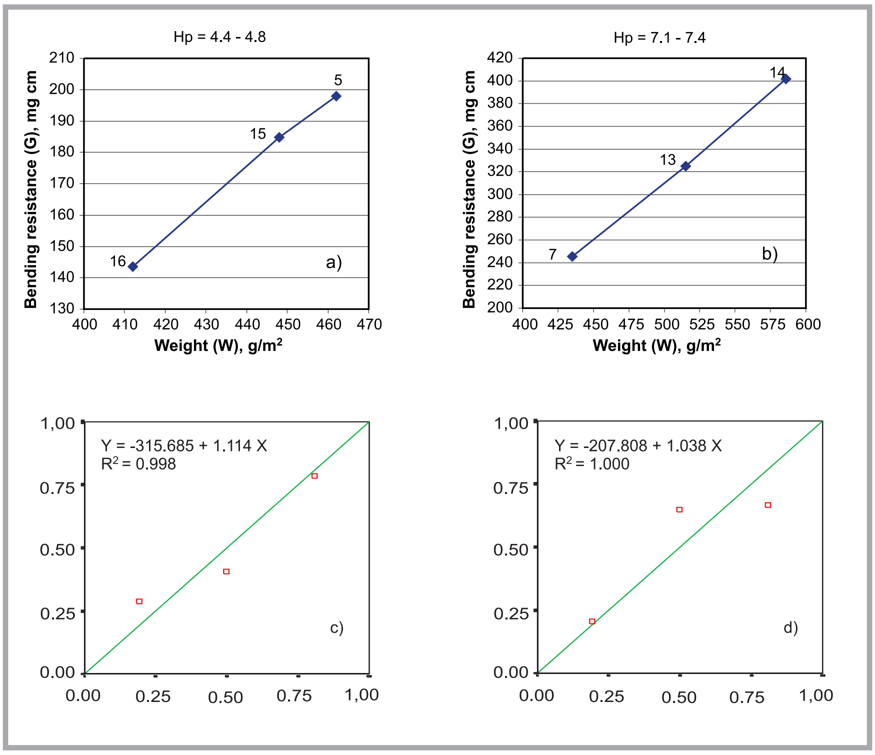

Figure 4. The variation of RB with dA of reference samples.

Table 4. Measured and predicted RB of selected reference samples.

Sample No	dA, g/m^2	RB, mg·cm		Sample No	d_A, g/m^2	RB, mg·cm	
		Measured	Predicted			Measured	Predicted
16	412.0	143.53	143.280	7	435.6	245.39	244.340
15	448.0	184.73	183.387	13	515.0	325.00	326.762
5	462.8	198.00	199.870	14	586.0	401.66	400.460

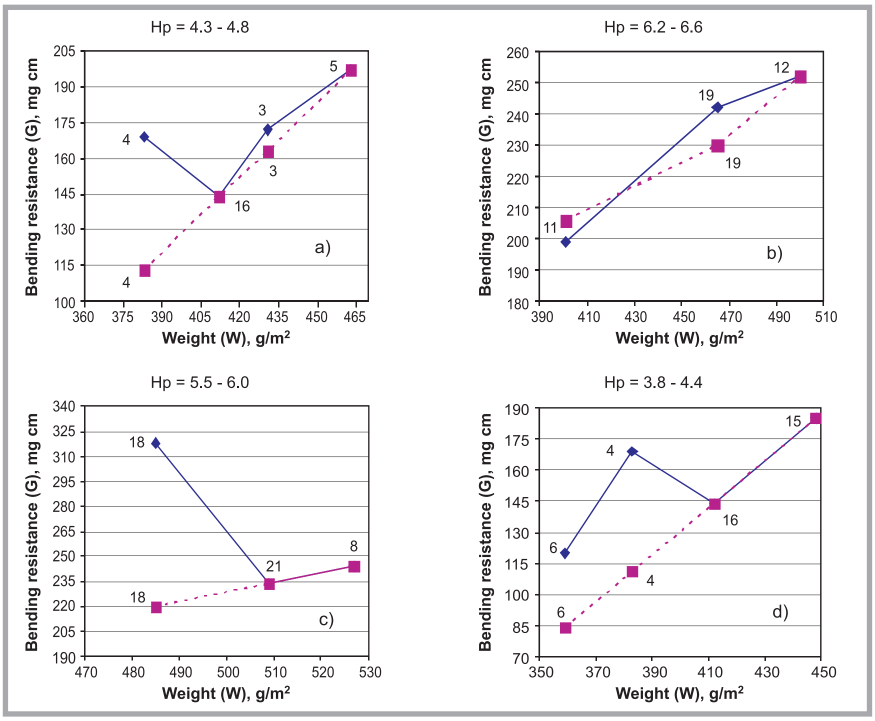

Figure 5. *The variation of RB with dA.*

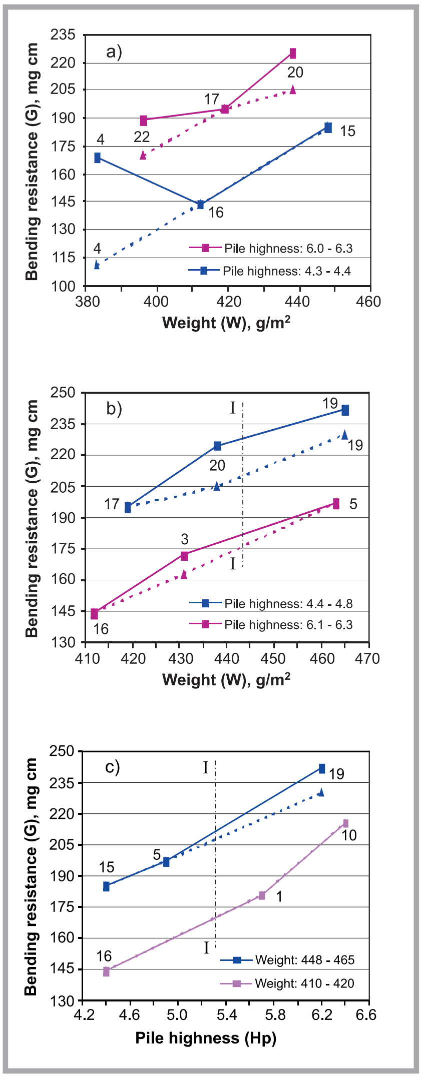

Figure 6. *RB-dA-Hp variation.*

erence samples with Hps between 4.2-7.8 and the d_A ranging between 412-435 and 500-526 g/m^2 have been selected, and the specific samples are marked on the lines. It is apparent from the figure that increases in both the fabric d_A and Hp cause an increase in fabric thickness, and so of the RB of the corresponding fabric or towel, as expected.

It seems that the rate of increase in RB with Hp is rapid for a low d_A interval; that is, the slope observed in this case seems to be steeper than that of the relatively higher d_A of the towels. The Hp in the high d_A is not as effective as in the lower d_A case. Hence with the high d_A, the effects of yarn numbers and densities on the RB are more pronounced than the effect of Hp. In the low d_A case, however, the Hp is found to have a significant effect on the SD. From this figure, it is easy to estimate the RB values for any Hp and d_A intervals by using the line marked as I-I. The variations exhibited in Figure 7 can be used as a model to predict the behaviour of any towel in terms of its RB.

It should be noted that the RB of sample 13 becomes about twice as large as that of sample 16. According to this experimental study, lower RBs are desirable for the improvement of the corresponding SD of the towels considered.

Examining the variations given in Figure 3 and 5, the production parameters (type of softener, colouration method and construction of weaving) have been found to significantly affect the RB. This effect was very pronounced for the velvet towels, sample 11 in Figure 3(b), the SD of which was found to be better than that of the un-cut pile towels. Since the Hps of velvet towels are shorter than that of the un-cut pile towel, fabric thickness in this case becomes less than that of the others; this is expected to be responsible for the lower resistance to bending than that of the un-cut pile towels.

Moreover, the RB of towels produced with dyed yarns was found to be higher than that of the towels dyed in fabric form, providing that the physical properties of towels considered to be the same (i.e. sample 18 in Figure 5(c)). Due to the shorter production processes applied after weaving towels obtained by dyed yarns in comparison with other towels, the dyed yarns seem to have less wear rate than that of the others, and hence the occurrence of less wear may cause a higher SD in the towels.

It has been inferred that the influence of the type of softener adopted to provide the necessary SD or the RB was primarily important, as in the case of samples 2, 3, 4 and 6 demonstrated in Figure 3 (a), (c) and Figure 5(d). Since the softeners have different chemical compositions, however, their effect on the softness of the towels shows considerable differences. From this experimental study, it was shown that the best SD has been ensured with cationic softeners, whereas the least softness was provided by anionic softeners.

Statistical analysis

The experimental results have been statistically evaluated by using the 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

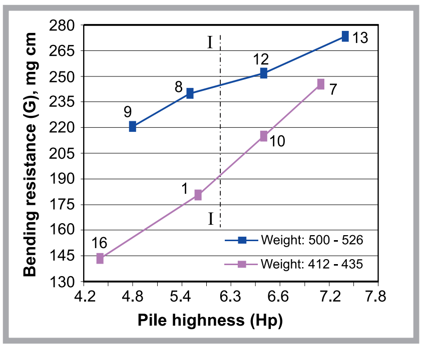

Figure 7. *The variation of RB with Hp.*

Table 5. *Statistical analysis of variance results, * : $F_{0.05,\ 3,\ 3}$ = 9.28, $F_{0.05,\ 1,\ 3}$ = 10.1, **: Critical value of the statistic $t_{cr} = t_{0.95,\ 6}$ = 1.94.*

Parameter	RB (SD)		
	F Values	% Contribution	Value of t-student statistic
Hp Statistical evaluation	9.6 > 9.28* significant	44.79	-,
d_A Statistical evaluation	32.32 > 10.1* significant	50.27	2.46 > 1.94** significant
Hp x DA	-	4.94	

Table 6. *The experimental and expected values of the selected samples; basic structures: all un-cut pile, colouration process: sample 18 - yarn, the remaining - fabric dyed, A - anionic, S - silicone, N - non-ionic.*

Sample Number	Grade	Measured RB, mg·cm	Expected RB, mg·cm	Variation, %	d_A, g/m^2	Hp	Type of Softener
6	1	120	85	29.1	358.8	3.8	A
16	2	145	145	0.0	412.0	4.4	S
4	3	168	110	34.5	383.3	4.3	A
3	4	172	160	6.9	431.1	4.8	N
12	5	251	251	0.0	500.0	6.4	S
13	6	273	273	0.0	515.0	7.4	S
18	7	318	220	30.8	485.3	5.7	S
14	8	401	401	0.0	586.0	7.1	S

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 RB (SD) variation of samples tested in terms of Hp and d_A in grams. In other words, the table shows that the Hp and d_A have significant effects on the towel's SD.

The data has also been evaluated to cover the relative importance of each source of variation in the ANOVA (including Hp and d_A), determined by portioning the total sum of squares for treatments as a percentage of the total sum of squares for the model adopted. The results thus obtained are also given in Table 5. The main effect of Hp accounted for 44.79% of the total variation in RB; whereas the d_A was a major factor contributing to 50.27% of total variation (F test gives the p-value of 0.0117). The interaction between Hp and d_A accounted for 4.94% of the variation in RB.

In addition to variance analysis, the t-student test has also been applied, and the RB of reference samples have been evaluated at two different d_A intervals. As seen from Table 5, the significant difference was determined in this case for the significance level of α=0.05.

The confidence intervals for the differences in two population means of RBs for different d_As have also been determined with a 95% level of confidence by using the following equation [18]:

$$\mu_1 - \mu_2 = (\bar{X}_1 - \bar{X}_2) \pm \sqrt{(k-1)F_{0.05}} \cdot s \cdot \sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \quad (3)$$

where:

s^2 : the residual variance in the ANOVA table

$F_{0.05}$: the critical value of F leaving 5% in the upper tail

k : the number of means to be compared. In the two-way ANOVA, the number of rows (in this case 2; here only the differences in means corresponding to the d_A of the towels are considered)

X_1, X_2 : sample means of RB concerning the d_A intervals

From this analysis, it has been found that $\mu_1 - \mu_2$ = 25.66, 91.1; this means that with 95% confidence, the differences between the two average RB values ($\mu_1 - \mu_2$) fall within the range of 25.66 – 91.1 mg·cm.

In this experimental study, in order to determine the influence of Hp or d_A on the softness of towels, a systematic experimental analysis was carried out as discussed above; the important results obtained are summarised in Table 6, in which the measured and expected RB of selected samples with the corresponding variation in percent were also given, as well as an assigned grade from the lowest softness to the highest softness. As seen from this table, the most convenient towel from the SD point of view is described in sample number 6. Both the expected and measured RB values of this sample are the lowest in those of the samples under investigation. According to this experimental study, it was determined that the towels were graded, according to their SD, from the lowest softness to highest softness, i.e. the fabric softness rank with 1 (sample 6) as the softest and 8 (sample 14) as the least soft.

Conclusions

After a series of experimental studies carried out on the performance of towels, the following conclusions can be drawn;

1. The experiments showed that, in general, increasing the Hp of the towel increased the RB, and a similar effect can be noted in the case of d_A. This increase is interpreted as a decrease in the SD of the towels, and in turn leads to an undesirable case.
2. In the present experimental work, the experimental approach we have developed is described here briefly. In this approach, some samples under investigation being processed by silicone softener, dyed in fabric form and type of un-cut pile towel were defined as the 'reference sample', and their properties were called 'reference properties'. In order to predict the real positions of the deviated points from the general trend explained above, a simple linear interpolation technique has been applied, expecting that these samples might have the properties matching the properties of reference samples. Hence, following the procedure defined above, the expected RB of the samples with the production properties different than those of the reference samples can easily be calculated.
3. It was inferred that the influence of type of softener used to provide necessary SD on the RB was of primary importance. The best SD was ensured with cationic softeners, whereas the least softness was provided by anionic softeners.
4. The SD of velvet towels was found to be better than that of the un-cut pile towels, as expected.
5. The RB of towel produced with dyed yarns was higher than the RB of towels dyed in fabric form, provided that the physical properties of towels were considered as the same.
6. It seems that the rate of increase in RB with Hp is rapid for low d_A interval, i.e. the slope observed in this case seems to be steeper than that of the relatively higher d_A of the towels.
7. By using the results displayed in this paper, it is possible to predict the

RB of any towel with any d_A and Hp values. In other words, the variations exhibited in Figure 7 can be used as a model to predict the behaviour of any towel in terms of RB.

8. It has been concluded that a towel of 3.8 Hp with 359 g/m^2 d_A produced using silicone softener, which is fabric coloured and has an un-cut pile type structure, may be suggested as the best type of towel in daily use from the point of view of the softener.

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