Tactile Feel of Washed Towels and Their Compression and Surface Properties

KIBAYASHI Yuriko*, SUKIGARA Sachiko*, YOKURA Hirokob,*

a Kyoto Institute of Technology, Matsugasaki, Sakyou-ku, Kyoto 606-8585, Japan
b Faculty of Education, Shiga University, 2-5-1 Hiratsu, Otsu, Shiga 520-0862, Japan

Received 16 May 2019; accepted for publication 3 July 2019

Abstract

The tactile evaluation was performed on 16 cotton towel samples that had been washed different numbers of times. Twenty-seven female and 24 male university students (20–24 years old) participated in the assessment. The surface and compression properties of fabrics were measured with the KES system. The tactile feels of softness and of smoothness were related to the geometrical roughness (SMD) and compression linearity (LC). The tactile feel was worse for washed towels with higher SMD and LC values. For washed towel fabrics, we found no significant correlation between the tactile feel and compression energy (WC). The results were related to the changes that occurred in the pile loop geometry during washing and caused matting of the pile. The changes were characterized by the ratio of ground fabric area observed in microscope images. To evaluate the initial resistance of the matted pile, we measured the frictional force (Ff) during movement of a friction contactor on the pile. The slope of the Ff peak (S-FfP) was a useful indicator for investigating the tactile change in towel fabrics after washing.

Key Words: Washed towel, Tactile feel, Compression property, Surface property, Frictional force

1. Introduction

Towels are used directly on the skin; thus, tactile comfort is an important factor related to the quality of towels and has been widely investigated [1-5]. The relationships between the sensory evaluation of towels and their physical properties have been investigated [2]. Nishimatsu et al. reported that sensory values were related to the compressive resilience and compressive modulus [3]. Takatera et al. used multiple regression analysis to show that the subjective value of smoothness increased with the compression resilience, and the subjective value of bulkiness increased with the compression energy [4]. Singh et al. developed the objective hand evaluation system for terry fabrics. They developed equations (BJ series) for predicting the hand values of terry fabrics using the surface and compression properties, and fabric weight and thickness [5]. These studies concluded that the compression and surface properties of towels are important physical properties for predicting a good tactile feel for towels.

The softness and smoothness of towels can be changed by washing treatments, such as the choice of detergent, softeners, and washing machine. Singh et al. investigated the effect of washing treatment on the properties of towels [6]. They suggested the optimum levels of loop density and loop length to increase life of towels. We are interested in the change in the tactile perception of consumers, which may occur if the same towel is washed repeatedly. We focus on what tactile changes make consumers decide to discard a towel and why. We describe the changes to the surface and compression properties of towels after various washing times. We present parameters for characterizing the changes to the pile structure that are closely linked to the tactile comfort of towels.

2. Experimental

2.1 Samples

Our main objective is to find the useful characterization method to estimate pile shape change after washing. We collected five commercially produced towels (A, B, C, D, and E, Table 1). Samples A, B, and C were woven using the same process with different yarn counts and density and were obtained from a company in Imabari, Japan. The pile ratios of the towels were 5.5, which is a relatively long pile. Sample D was obtained from a
KIBAYASHI Yuriko, SUKIGARA Sachiko, YOKURA Hiroko

Table 1  Basic characteristics of towel samples.

| No. | Yarn Counts (tex) | Pile Ratio | Twist angle of Pile yarn (degree) | Ground yarn Density | Thickness (mm) | Weight (g/m²) |
|-----|------------------|-----------|----------------------------------|---------------------|---------------|--------------|
|     | Warp  | Weft  | Pile   | Warp (ends/cm) | Weft (pick/cm) |              |             |
| A   | 14.8/2 | 36.9  | 19.7   | 16.8           | 11.9           | 21.7         | 4.94         | 313           |
| B   | 29.6   | 29.6  | 19.7   | 14.4           | 11.9           | 21.7         | 4.72         | 315           |
| C   | 29.6   | 29.6  | 29.6   | 6.7            | 17.7           | 20.7         | 4.80         | 272           |
| D   | 29.6   | 19.7  | 29.6   | 20.7           | 11.9           | 13.8         | 4.97         | 310           |
| E   | 29.6   | 29.6  | 29.6   | 3.9            | 25.2           | 10.6         | 2.96         | 216           |

company in Izumiotsu, Japan, and its pile ratio was 5.5. This kind of towel is preferred by Japanese consumers, although its tactile feel tends to change without careful washing. Sample E was a typical Japanese towel with the pile ratio of 3.9, thinner than the other samples. Sample E was chosen as the reference sample to estimate preferences.

The five towel samples were washed with a front-loading home washing machine (VR-N1100, National) under the maker’s standard conditions: washing, 20 min; rising, twice for 10 min each. Washing was carried out at around 25 °C using the standard detergent specified by the Japan Association for the Functional Evaluation of Textiles (JAFET) without softener. The laundry load was 2.8 kg based on the maximum capacity of the washer (10kg). A total of 10 towels and 10 cotton underwear-shirts were used to set the laundry load as 2.8 kg. Washed samples were hung up to dry in a room at 23 to 27 °C. The numbers of washing cycles were 0, 15, and 20 for samples A and C; 0, 1, 5, 15, and 20 for sample B; 0, 1, 3, and 5 for sample D; and sample E was not washed. Because the pile shape change is important to consider the tactile feels, we need the various pile shape which occurred during washing. In this sense, numbers of washing time were not constant. Finally, the 16 towels were used for physical and tactile evaluation.

2.2 Subjective Hand Evaluations

(1) Semantic differential method for assessing preferences

The tactile feel of towels was assessed by 27 female students and 25 male students (20–24 years old). They evaluated 16 towels by touching them by hand. The participants were asked only to judge the tactile feel. Evaluation paired words were “soft/hard,” “smooth/rough,” “want to use/not want to use”, and “prefer/not prefer” using a scale from -2 to +2 according to the semantic differential method. Evaluations were performed in random order. The participants compressed the pile surface to evaluate “softness”, and slid their fingers over the pile surface to evaluate “smoothness”. To evaluate “want to use” and “preference”, no specific assessment methods were given. We examined the correlation between the individual rating scores and the mean scores of the subjective assessments and excluded data from participants whose scores had no significant correlation with the mean rating score at the 0.05 significance level. Their assessments tended to be somewhat different from those of majority of participants. We used the mean rating score of the

Table 2  Characteristic values of surface and compression properties and measuring conditions.

| Properties | Symbol | Characteristic Value | Unit | Measuring Conditions |
|------------|--------|----------------------|------|----------------------|
| Compression| LC     | Linearity            | none | Maximum pressure: 4.9 kPa. |
|            | WC     | Compression energy   | J/m² | Rate of compression: 0.2 mm/sec. |
|            | RC     | Resilience           | %    | Compression indenter: 2 cm² circular plate. |
| Surface    | MIU    | Coefficient of friction | none | Contact area of sensor for MIU: 10 x 10 mm. |
|            | MMD    | Mean deviation of MIU | none | Contact force: 0.49N, Velocity: 1 mm/sec. |
| SMD        | Geometrical roughness | μm | Sensor: a piano-wire with 0.5 mm diameter and 5 mm length. |
|            |        |                      |      | Contact force: 0.05N, Velocity: 1 mm/sec. |
| Thickness  | T0     | Thickness at 49 Pa pressure | mm | |
| Weight     | W      | Weight per unit area | g/m² | |
subjective assessments by 27 female students and 24 male students as the tactile feel of the samples for the analysis.

(2) Normalized ranking method for evaluating softness and smoothness

We conducted a sensory evaluation, which focused on softness and smoothness, using the normalized ranking method [7]. As well as the rank of the sample, we can show the significant difference between the samples by using this method. The experiments were designed to clarify the factors contributing to softness and smoothness; thus, samples A, B, and C washed 0, 15, and 20 times, giving a total of nine samples, were used. The participants were 23 female students (19–23 years old). To evaluate softness, the participants were asked to rank the samples according to the degree of softness when they compressed the samples by hand. Ranks were given on the scale of 1 – 9 (1: being the soft and 9: being the most hard). To evaluate smoothness, they were asked to rank the samples according to the degree of smoothness when they slid their fingers over the pile surface. Ranks were given on the scale of 1 – 9 (1: being the smooth and 9: being the most rough).

2.3 Surface and Compression Properties, and Air Resistance

Table 2 shows the compression and surface parameters and the measurement conditions. The compression properties were measured with the compression tester (KES-F3, Kato Tech Co., Ltd.) under the standard conditions [8]. The frictional properties, mean frictional coefficient (MIU) and fluctuation of mean frictional coefficient (MMD), were measured with a surface tester (KES-SE, Kato Tech Co., Ltd.) using a contactor (10 × 10 mm) under an applied load of 0.5 N [5]. In the measurement of geometrical roughness (SMD), a U-type contactor (one piano wire 0.5 mm in diameter) was moved on the towel surface under a load of 0.05 N. The U-type sensor detects geometrical roughness and frictional force simultaneously [9]. In Figure 1, the frictional force (Ff) along the towel warp direction is plotted against the movement distance for sample C before and after 20 washing cycles. A large increase in Ff was observed for the washed sample. The increase corresponded

![Fig. 1 Profiles of frictional force Ff along the towel surface for sample C. ○: before washing; ●: after 20 washing cycles.](image-url)
to the geometrical change in the pile caused by washing and we created a parameter to describe the initial resistance of pile, \( S-FfP \), which was calculated from the slope in the horizontal displacement range of 0 to 10 mm (Figure 1). The frictional forces along the towel warp direction were measured in ten places in each sample. We measured seven clear \( S-FfP \) values in each sample. The air resistance values (\( R \)) were measured with an air permeability tester (KES-F8AP, Kato Tech Co., Ltd.).

3. Results and Discussion

3.1 Physical Properties of Towels

Table 3 shows the fabric air resistance, compression, and surface properties of 16 towel samples. For all samples, the values of air resistance (\( R \)) and fabric weight (\( W \)) for washed samples were larger than those of the unwashed samples. This is because of the increase in weave density. These changes may be attributed to the fact that the total weight of towel decreased due to small fibers falling out during washing. The values of compression linearity (\( LC \)) and \( SMD \) increased with the increase in the number of washing cycles. These results were related to the changes in the pile loop geometry and orientation. To measure the pile and ground fabric areas on the towel surface, 3D digital microscope images (VR-3100, Keyence Co., Japan) were used and the relative distribution of the fabric height was analyzed. Figure 2 shows the surface of sample C20, which was sample C after 20 washing cycles. The color difference in Figure 2(b) indicates the height distribution from the base thickness. We calculated the ratio of the ground fabric area from the total area to extract the change in pile. If the pile was matted together, more ground weave area was exposed. Figure 3 shows the relationship between the ratio of ground fabric area and the washing cycles. The ratio of the ground fabric area increased as the number of washing cycles increased. Samples A0, B0, and

![Image](image_url)

(a) Surface of towel C20  
(b) Distribution of pile height

Fig. 2  Microscope images of the surface (a) and distribution of height of the pile (b) of sample C20.

![Image](image_url)

Fig. 3  Relationship between the ratio of ground fabric area and the number of washing cycles.
C0 had the same pile ratio and ground warp density, but different weft ground densities. Sample A, which had a higher loop density, showed a smaller increase in the ground fabric area than samples B and C. High loop densities, such as that in sample A, maintain the initial pile shape; therefore, a smaller increase in ground fabric area was observed. In contrast, the ground fabric area of sample D increased quickly after five washing cycles. Comparing the ground fabric areas of samples B and C showed that washing formed more pile clumps in sample C, which had a lower pile density.

3.2 Tactile Feel and Physical Properties of Towels

Table 4 shows the correlation coefficients between the tactile feel of all towel fabrics, including pre-washed fabrics, and the compression and surface parameters. We used the mean rating score of the subjective assessments of 51 students as the tactile feel of the samples. The correlation between “smoothness”, “want to use”, and “preference”, and $MIU$, $SMD$, and $LC$ were observed at a 1% significance level. The “softness” was correlated with $SMD$ and $LC$ at a 1% significance level, and $MIU$ and $MMD$ at a 5% significance level. In previous studies [1-5], the tactile feel of unwashed towels was strongly correlated with the compression energy ($WC$). However, for washed towel fabrics, there was no significant correlation between tactile feel and $WC$. The thickness and $WC$ values of the washed samples were larger than those of the unwashed samples, and the $LC$ values of washed samples were also larger than those for the unwashed samples. The loop geometry and orientation became disordered and causing the loops to lean and form clumps. These changes were related to the loop density and were reflected in the increase of $WC$. However, participants did not report a good tactile feel. Thus, $WC$ was not a useful characteristic value for evaluating the changes in the pile. Further analysis was carried out to confirm this result.

The primary hand values of fullness/softness were calculated by using the conversion equations (BJ series) reported by Singh et al. [5]. In these equations, the compression and surface parameters, thickness, and weight of the fabrics are used. In Figure 4, the calculated primary hand values of fullness/softness are plotted against the evaluated “softness”. For the unwashed samples, there was good agreement between the subjective evaluation value and the calculated fullness/softness value. In contrast, the evaluated “softness” value of washed samples deviated from the calculated fullness/softness value. We concluded that other dominant physical characteristic values are required to evaluate the washed samples.

A significant correlation between $LC$ and the subjective evaluation was observed (Table 3). Figures 5 and 6 show the $LC$ values plotted against the “smoothness” and “want to use” evaluations, respectively. Towels with a small $LC$ value were expected to provide a smooth, soft hand, and resulted in the “want to use” evaluation. The evaluations of male and female students are compared in Figure 6. The female students were more sensitive
Fig. 5  Relationship between the subjective hand evaluation of “smoothness” and $LC$ of towels.

Fig. 6  Relationship between the subjective hand evaluation of “want to use” and $LC$ of towels. ○: male students, ●: female students.

Fig. 7  Subjective ranking of “softness” (a) and “smoothness” (b). **1% significance level, *5% level.

Fig. 8  Relationship between the subjective evaluation of smoothness and the slope of the peak of frictional force ($S-F/P$) of towels.
to the change in the tactile feel of fabrics. These results show that washed towels with $LC$ values larger than 0.41 were evaluated as having a rough, hard hand.

Figure 7 shows the subjective ranking of “softness” and “smoothness” for samples A, B, and C. Before washing, sample C0, which had a smaller weft yarn density and yarn count, produced a soft, smooth hand. As the number of washing cycles increased, the evaluated “softness” and “smoothness” of sample C20 decreased greatly. Sample A20, which had higher weft yarn density and yarn count, had a significantly softer, smoother hand than C20. These results are related to the geometrical changes in pile shown in Figure 3.

### 3.3 Relationship between the Pile Resistance and Tactile Evaluation

Figure 8 shows the relationship between the subjective evaluation of “smoothness” and the slope of the $F_f$ peak ($S-F_fP$) of the samples, as shown in Figure 1. Towels with a small $S-F_fP$ were predicted to have a smooth hand. The correlation coefficients between the tactile feel of $S-F_fP$ were -0.88 for “softness”, -0.89 for “smoothness”, -0.89 for “want to use”, and -0.88 for “preference”. These correlation coefficients were higher than those obtained for $LC$ (Table 4). The slope of the $F_f$ peak was a useful indicator for the tactile changes in towel fabrics after washing.

### 4. Conclusions

In this study, we presented new parameters to characterize the changes in the pile structure, which are closely linked to the tactile comfort of towels. Tactile evaluation of cotton towels was performed for 16 samples that had been washed different numbers of times. The tactile feel of the towels was assessed by 27 female students and 24 male students (20–24 years old). The surface and compression properties of fabrics were measured with a KES system.

The tactile feel of “softness” and “smoothness” were related to $SMD$ and $LC$. The tactile feel became worse when the $SMD$ and $LC$ values increased with the geometrical changes of pile and matting. For washed towel fabrics, we found no significant correlation between the tactile feel and $WC$ because washing disturbed the loop geometry and caused matting of the pile. The changes in the pile that occurred during washing were characterized by the ratio of the ground fabric area measured in microscope images. The geometrical change in the pile caused by washing was described by a new parameter, the initial resistance of pile ($S-F_fP$). The $S-F_fP$ value is a useful indicator for investigating the tactile changes in towel fabrics after washing.

### Acknowledgements

This work was supported by JSPS KAKENHI Grant Numbers JP15H01764 and JP18K02187.

### References

[1] Singh JP, Verma S (2016) “Woven Terry Fabrics”, Woodhead Publishing, UK
[2] Nishimatsu T (1984) Textile Research Journal, 54, 699-705. https://doi.org/10.1177/004051758405401101
[3] Nishimatsu T, Sawaki T (1982) Sen'i Kikai Gakkaishi (Journal of the Textile Machinery Society of Japan)(predecessor journal of Journal of Textile Engineering), 35, T146-T152 (in Japanese). https://doi.org/10.4188/transjmsj.35.10_T146
[4] Takadera M, Kunihiro S, Yazaki Y, Otake A, Simizu Y (2005) Journal of Japan Society of Kansei Engineering, 5, 103-110 (in Japanese). https://doi.org/10.5057/jjske2001.5.3_103
[5] Singh JP, Behera BJ, Matsudira M (2014) The Journal of The Textile Institute, 105, 467-476. http://doi.org/10.1080/00405000.2013.825519
[6] Singh JP, Behera BJ (2018) Indian Journal of Fibre & Textile Research, 43, 415-420. http://op.niscair.res.in/index.php/IJFTR/article/view/15399
[7] Fukuda T, Fukuda R (2009) “Ningen-kougaku guide”, 41-71, Scientist-press, Tokyo (in Japanese)
[8] Kawabata S (1980) “The standardization and analysis of hand evaluation”, The Textile Machinery Society of Japan, Osaka
[9] Kawabata S, Niwa M, Wang F (1994) Textile Research Journal, 64, 597-610. https://doi.org/10.1177/004051759406401008