Visualization of fabric fluffiness and dryness —Evaluation of laundry detergents using X-ray computer tomography—

Yukari Sekine*

1. Introduction

For manufacturers who market a wide range of products, including household products, pharmaceuticals and/or nutraceutical products, it is important to communicate the characteristics of their products to consumers. This often requires a good evaluation technique that can show the product characteristics intuitively. X-ray imaging techniques, which can visualize the internal structure of a sample non-destructively, are now widely used in academic, medical, and industrial applications. The combination of X-ray and Computed Tomography (CT), which can re-construct the internal 3-dimensional structure of a sample through numerical computation of the transmission data, is called X-ray CT, which is used in a variety of processes, from R&D to quality inspection. Herein, we report an application of the X-ray CT technique for evaluating the performance of laundry detergents and how the results were successfully used for the promotion of a detergent product[1].

2. Background of the Performance Evaluation of Detergents

Japanese laundry style has changed recently due to an increase in dual-income families, changes in living situations and the desire to avoid pollen and PM2.5. In order to find out what makes laundry better for people, we surveyed Japanese consumers and found that the rate of people who dry their laundry indoors is increasing each year (Lion Corp., unpublished, 2017, $N=1400$). On the other hand, about 90% preferred to dry their laundry outdoors (Lion Corp., unpublished, 2014, $N=1400$) because they felt that outdoor drying produces better texture for the laundry than indoor drying[2]. We further analyzed the factors contributing to the preferred texture, which one respondent called "the texture of laundry dried outdoor on a sunny day (outdoor-dried texture)." This survey revealed that there were two major sensory factors: "fluffiness" and "dryness" (Fig. 1)[2]. Therefore, we focused on these two attributes and developed a new laundry detergent that enhanced these textures. However, it was difficult to communicate the performance of this new product to consumers, since we did not have an intuitive way to indicate "fluffiness" and "dryness." Accordingly, we utilized the X-ray CT technique to visualize the characteristics of the laundry in order to help potential consumers better understand what the product would provide.

* Advanced Analytical Science Research Laboratories, Research & Development Headquarters, Lion Corporation.

3. X-ray CT Systems and Measurement Conditions

Two different X-ray CT systems, the CT-Lab GX (Rigaku Corporation) and the nano3DX (Rigaku Corporation) were used. The CT-Lab can measure a wide range of materials, from organic materials to light metals, due to its variable tube voltage, and it has a wide field of view. These features make the CT-Lab useful especially for investigating the structure of large and/or heavy samples. The nano3DX, on the other hand, has better performance in analyzing the finer structures of the sample because of its high resolution, although its tube voltage is fixed. We used these two instruments depending on the purpose of the observation.

A bath towel made with 100% cotton was chosen as the sample, as it was expected to give clearer differences in texture under different drying conditions. Measurements with the CT-Lab were made with a tube voltage of 30 kV, a tube current of 200 μA, and a scan time of 14 min without an X-ray filter. Scans with the nano3DX were done using a Cu target (40 kV and 30 mA) and the L1080 detector unit (resolution 1.1 μm/pixel).

4. Visualization of "Fluffiness"

We focused on the thickness of the bath towel samples as the indicator of "fluffiness." Figure 2 shows the evaluated thicknesses of the samples that were washed and dried under different conditions[3]. Indoor drying was conducted at 20°C and 65%RH. The thicknesses of the 140 cm × 70 cm towels folded into 16 layers were measured using a Digimatic Height Gauge (Mitutoyo Corporation). The sample washed with the newly developed detergent and dried indoors produced a thicker towel than the sample washed using our current detergent and dried outdoors. On the other hand, the sample washed using the current detergent and dried indoors was thinner.

To obtain an intuitive image showing the fact that the newly developed detergent produces a thicker towel than our current one does, even with indoor drying, we imaged the fiber structures of these two samples

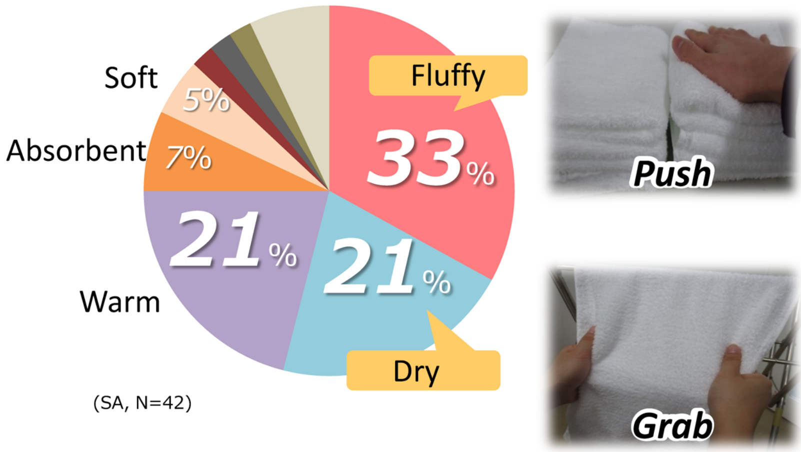

Fig. 1. Survey Result: What textures do consumers like in laundry dried outdoors? (single answer). The pictures are for reference only.

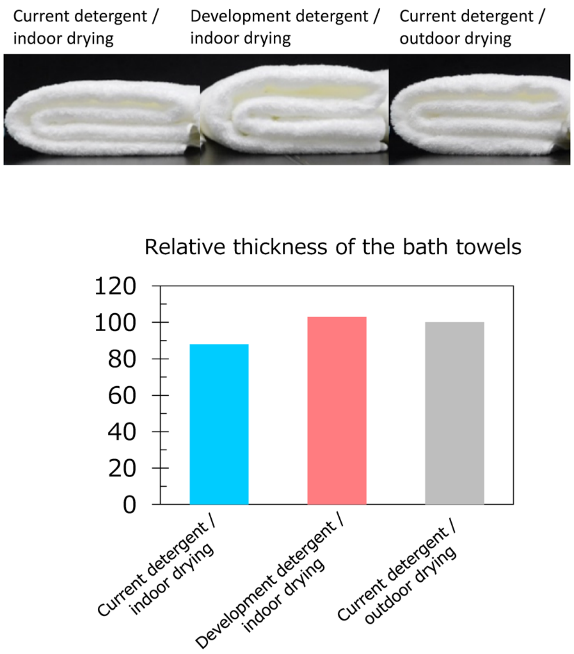

Fig. 2. Thickness of the bath towels processed by different detergents and under different drying conditions.

using the CT-Lab and the nano3DX. Figure 3 shows the obtained CT images of the samples, which were cut into a 2 cm × 2 cm piece each, using the CT-Lab. The towels, drawn in gray in the images, showed their characteristic pile structures with loops of yarn. Images of the individual pile yarn of each sample are shown in the inserts of Fig. 3. It is found that the towel washed with the current detergent and dried indoors had flatter and more twisted strands, and their pile loops were less upright. On the other hand, the sample washed with the new detergent and dried indoors had more swollen strands with wider spaces between them, and the pile loops were more upright. The one washed using the current detergent and dried outdoors was found to have qualitatively similar characteristics to the second sample. These result suggest that wider spacing between the strands and more upright shapes of the yarn loops

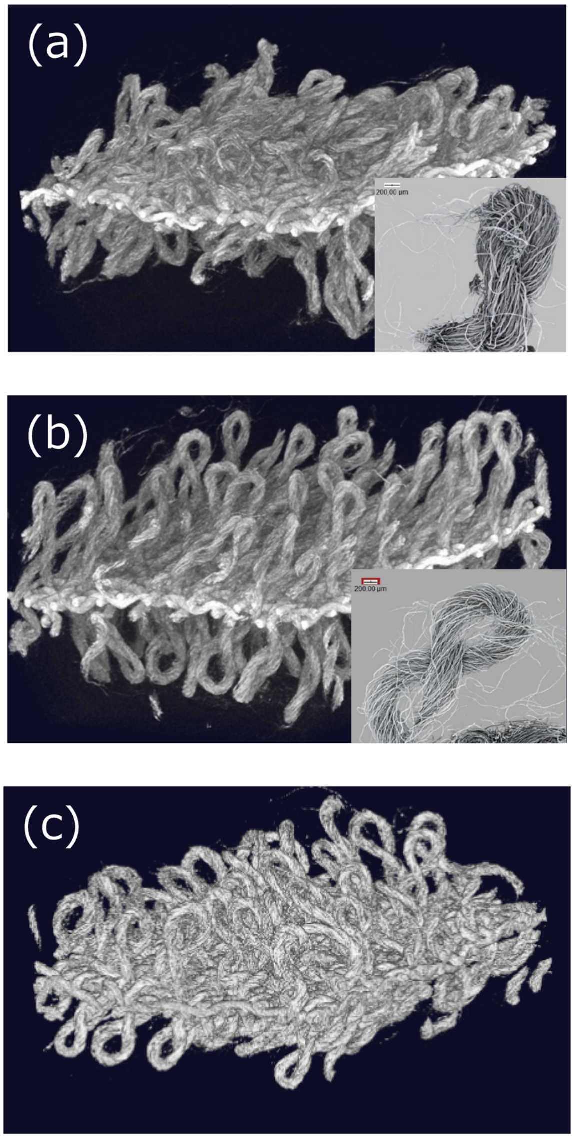

Fig. 3. X-ray CT images of the bath towels processed by different detergents and under different drying conditions. (Inserts) Images of a single pile of each towel. (a) Our current detergent / indoor drying, (b) newly developed detergent / indoor drying, (c) our current detergent / outdoor drying.

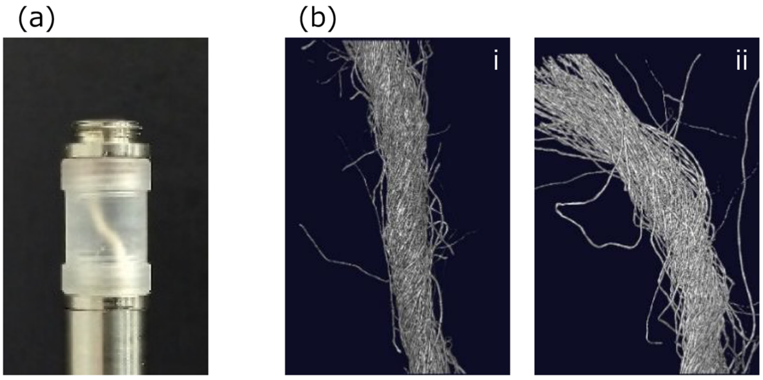

Fig. 4. Images of single strands after different processes. (a) Sample mount, (b)-i current detergent / indoor drying, (b)-ii newly developed detergent / indoor drying.

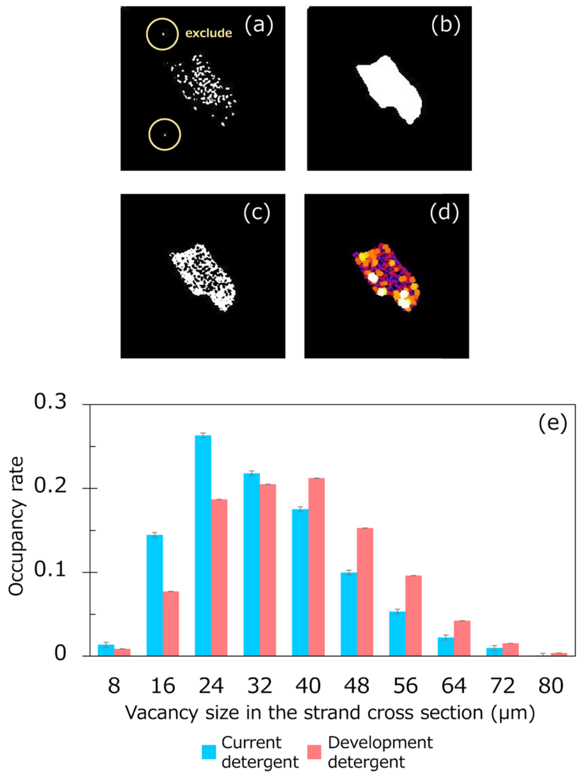

Fig. 5. Vacancy-size measurement for single strands after different processes. (a)–(d) Steps for the image processing. (a) Removing the isolate fibers that do not belong to the strand of interest, (b) applying a mask to extract the cross section of the strand, (c) overlaying the image of the fibers on the mask, (d) extracting the vacancies, (e) vacancy-size distribution in terms of the occupancy rate in the cross section of the single fiber.

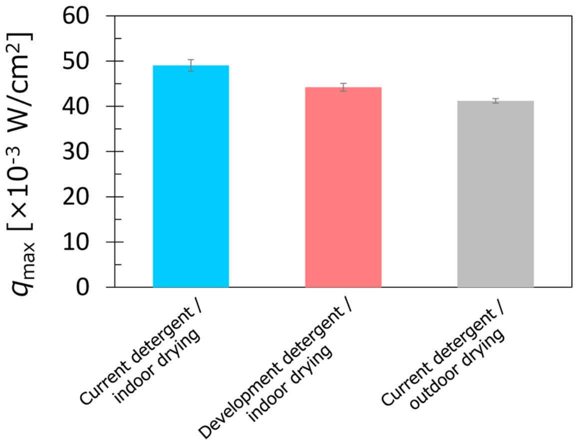

Fig. 6. Maximum heat flux for the bath towels after different processes.

are the key factors contributing to "fluffiness."

In general, the softness and moisture-retaining property of cotton yarns originate in the hollow (lumen) structure of the fibers and the insulation by the air retained in the spaces between the naturally twisted strands[(4)]. Also, because it is known that outdoor drying changes the twisting of the strands and makes the air in the lumens in the fibers expand, resulting in swelling of the cotton strands[(4)], we theorized that the outdoor drying produces "fluffiness" by expanding the volume and the thickness of the pile texture due to heat and wind. Therefore, we conducted a more detailed observation on the fiber structure, focusing on the retained air, which is expected to play an important role in realizing "fluffiness."

Sample towels were washed separately using the new and current detergents, and both were dried indoors. A single strand was taken from each of the towels with tweezers and cut into a 5-mm long piece, which was fixed onto a sample stage using double-sided tape as shown in Fig. 4(a), and then scanned using the nano3DX. The obtained images are shown in Fig. 4(b). It is clearly seen that the strand washed using the newly developed detergent (Fig. 4(b)ii) is thicker than the one processed with the current detergent (Fig. 4(b)i). It is believed that the base surfactant used in the new detergent changed the characteristics of the individual fibers and made the strands retain more air. To investigate the vacancy in the strands, we conducted a further analysis of the cross-section structure of the strands. A cross-section image of a single strand was chosen from the obtained 3D data, and the isolated single fibers that do not belong to the strand of interest were removed (Fig. 5(a)). An

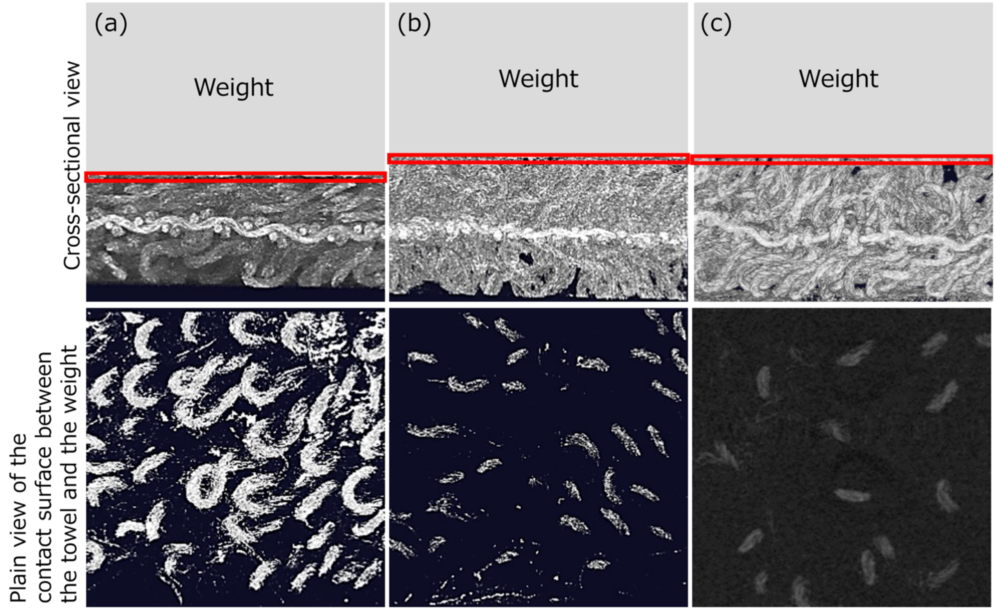

Fig. 7. X-ray CT images of the bath towels after different processes and the touching surfaces. (a) Current detergent / indoor drying, (b) newly developed detergent / indoor drying, (c) current detergent / outdoor drying.

image mask was applied to focus only on the cross section of the strand (Fig. 5(b)). Then the fiber cross-section image was overlaid on the mask (Fig. 5(c)) to extract the vacant sections. Figure 5(d) shows the vacant sections color-coded according to their sizes. The vacancy-size distributions in the two samples are shown in Fig. 5(e). The median vacant size was 30.0 μm and 37.8 μm for the samples processed with our current and the newly developed detergents, respectively. This result indicated that the new detergent resulted in wider spacing between the fibers. These results suggest that the newly developed detergent expands the spacing between the fibers, resulting in swelling of the strands, which makes the whole towel fabric thicker and gives the user "fluffiness."

5. Visualization of "Dryness"

Consumers feel that laundry does not dry completely on a cold winter day, even after a longer period of drying. This feeling was thought to indicate that the actual feeling of "dryness" is related to the cold feeling of the towel. Therefore, we measured the maximum heat flux, q_{max}, of the sample towels. The measurements were conducted using Thermo Labo IIB type KES-F7 high-speed high-precision thermal property measurement system (Kato Tech Co., Ltd.)[(3)]. The result showed that, under indoor-drying conditions, the newly developed detergent gave a smaller q_{max} than the current detergent (Fig. 6). It should be noted that the new detergent with indoor drying gave a q_{max} value closer to that of the current detergent with under outdoor-drying conditions. It is known that the larger the q_{max} of a material is, the cooler it feels when you touch it. Thus, it is concluded that washing a towel with the newly developed detergent gives laundry a better "dryness."

We attempted to image a contact area to show the heat flux from touching the towel with a hand. Total heat flow from touching a hand to the towel is proportional to the contact area if the temperature difference between the hand and the towel is constant. To investigate the heat flow in more detail, we measured the contact area using the CT-Lab. A weight was put on the sample towel to apply a pressure of 2.7 gf/cm^2 to simulate the touch by hand, and the contact area between the surface of the weight and the towel strands was analyzed from the 3D data. The result showed that, under indoor-drying conditions, the newly developed detergent gave smaller subduction of the weight and thus a smaller contact area than the current detergent (Fig. 7). The result for the newly developed detergent under indoor-drying conditions was rather closer to that of the current detergent under outdoor-drying conditions. These results suggested that the new detergent makes a towel more resistant to compression, keeping the contact area between the strands and the hand small. This, along with the smaller q_{max} it gives, helps give the towel the feel of "dryness".

6. Conclusion

We measured X-ray CT images that can communicate the "fluffiness" and "dryness" of laundry to consumers as a feature of detergents. A more effective product promotion would be possible by a combination of the scientific description and the intuitive presentation of the product performance. We are planning to examine a wider variety of instruments and physico-chemical properties that can be utilized for enhancing the ability to give a direct performance impression to consumers and ultimately to help provide them with household products that can improve their lives.

References

(1) Yukari Matsunaga, Ai Tanaka, Takuya Tsutsui, Yasushi Kakizawa: *Preprint of 79th Discussions on Analytical Chemistry, Japan*, (2019), 51.

(2) Aiko Tai, Shota Okeda, Tsuyoshi Terabayashi, Ai Tanaka, Yoichiro Kohno, Hiroyuki Masui, Toyonori Nishimatsu, Hiroyuki Kanai: *Preprint of the Annual Meeting of the Society of Fiber Science and Technology, Japan*, **73** (2018), 207.

(3) Tomonori Nishimatsu, Hiroyuki, Kanai, Megumi Fuiwara, Kyouhei Takahashi, Nobuyuki Kishine, HatsumeFujita, Asako Furuta and Ayako Masukawa: *Journal of Textile Engineering*, **60** (2014), 91–98.

(4) Hirofusa Shirai: *Sen'i Gakkaishi*, **59** (2003), 191–195 [in Japanese].