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Factors of increase in demand of elastic garments in Japan
日本における伸縮性素材の衣服の普及

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Abstract: Many people in Japan wear clothing made from knitted fabrics now and wear clothing made from woven fabrics until approximately fifty years ago. The factors of increase of elastic garments were investigated from the viewpoints of clothing performance, comfort of the clothing, cultural aspect and industrial aspect. The various measurement results of different fabrics indicate that the difference between the properties of woven fabrics and knitted fabrics, and the difference between the properties of knitted cotton fabrics and knitted polyester fabrics. Further, the structure of the elastic woven fabrics was also investigated. It can be considered that the changes in human sentiment, economic growth and development of technology affected each other and increased popularity of elastic fabrics in Japan.

Keywords: elastic clothing, woven fabric, knitted fabric, load vs. elongation curve, residual strain rate

1. Introduction

Clothing including suits, shirts, jeans and school uniforms are usually made from woven fabrics. In contrast, sweaters, t-shirts, hoodies, sweat shirts and sports clothing are generally made from knitted fabrics. It is said that woven fabrics have been used approximately ten thousand years ago. People obtained fibers from plants, made yarns using the fibers and made fabrics using the yarns by weaving. On the other hand, knitted fabrics are considered to have been invented approximately two thousand years ago. The woven fabrics and knitted fabrics have different structures. The woven fabrics are structured using warp and weft crossings that are at right angles and do not tend to stretch. Thus, clothing made from woven fabrics can maintain their silhouette and shape. In contrast, knitted fabrics are structured by knitting yarn in the shape of a loop and offer good elastic properties. Consequently, clothing made from knitted fabrics can change their shape in accordance with the movements of the human body.

The gym uniforms used in the gym classes are designated in most of elementary and junior high schools in Japan. Then, knitted fabrics are usually used to fabricate the gym uniforms. Further, knitted fabrics are often used for making outer garments such as t-shirts, polo shirt and sweat shirts at the present day. However, gym uniforms and everyday clothing were made from woven fabrics up to approximately fifty years ago[1)].

Knitted fabrics have a long history dating back to 17th century when they were used for creating garments such as Japanese tabi-socks and long-johns[2)]. Knitted wool including sweaters and cardigans has already existed before the Second World War (1939-1945). However, “cut and sew” was limited for making innerwear and were not used for making outer clothing; “cut and sew” is the clothing made from knitted fabric which was used as textile by cutting and sewing in the same manner as that of the woven fabric. It was only since the “knit boom” of the 1960s that knitted fabrics began to be frequently used for making everyday clothing[1)].

The usage of “cut and sew” in Japan has exhibited a remarkable progress over the previous fifty years. In addition, skinny jeans and stretch pants made of woven fabrics and possess elasticity appeared in recent years. The purpose of this study was to investigate the reason because of which elastic fabrics have become rapidly popular in Japan from the viewpoints of clothing

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performance, comfort of clothing, the cultural aspect and industrial aspect.

2. Materials and Methods

2-1. Measurement of the tensile strength and breaking extension of the sample fabrics

Three types of woven fabrics and five types of knitted fabrics were investigated. The fabric samples shown here included woven cotton fabric (EPI/PPI: 45/44, weight: 104.6 g/m^2, thickness: 0.37 mm), knitted cotton fabric (weft knitting, CPI/WPI: 78/48, weight: 139.3 g/m^2, thickness: 0.40 mm) and knitted polyester (PET) fabric (weft knitting, CPI/WPI: 45/48, weight: 229.3 g/m^2, thickness: 1.09 mm). The substrate samples were cut into pieces that were 25 mm wide and were approximately 240 mm long. The woven fabrics were studied in three directions (longitudinal, lateral and diagonal), and the knitted fabrics were investigated in two directions (wale and course). The tensile strength and breaking extension were measured in accordance with the Japan Industrial Standard method (JIS) L 1096 8.14, using a tensile testing machine (Shimadzu Autograph S-type S-500-C type). The length of the sample between the grips was 100 mm, and a tensile speed of 50 mm/min was used. The load vs. elongation curve was measured until the sample tore. A minimum of four samples were tested under each of the aforementioned conditions to verify the reproducibility of the measurements, and an adequate graph was used in the results and discussions.

2-2. Measurement of the residual strain ratio

Clothing is not deformed enough to force it to tear under ordinary usage. However, small change of the clothing shape is considered to occur frequently in accordance with movements of the user. To numerically express the change, residual strain ratio of the fabric samples was investigated. The method is depicted in Figure 1 and includes the following steps: (a) the first weight, which straightens the substrate sample, is applied to a substrate sample, and the sample is marked at 20-cm interval; (b) 200 g of a load is applied to the substrate sample for five minutes; (c) the first weight and the load are subsequently removed from the substrate sample, which is further allowed to set for five minutes; (d) the first weight is again applied to the substrate sample, and the length between the marks is measured and named as L (cm). This measurement is performed for at least three samples of each substrate. Further, the average value of L was substituted in the following formula to calculate the residual strain rate of each substrate sample.

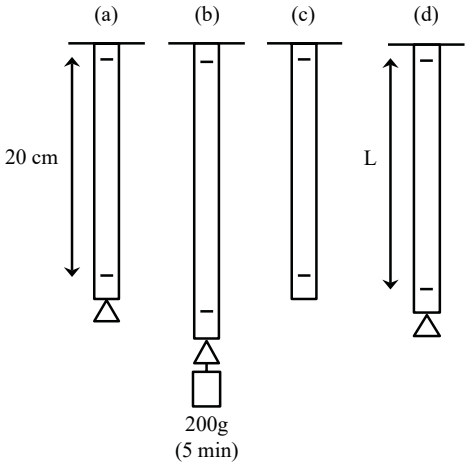


Figure 1. Method to measure of residual strain rate.

Residual strain ratio (%) = {(L – 20)/20} × 100

2-3. Observation of the fabric, yarn and fibers

Two types of trouser which are commercially available and are made from elastic woven fabrics were studied. The composition and the yarn structure of them were investigated. The trousers included slacks (PET 60% / rayon 34% / polyurethane (PU) 6%) and skinny pants (cotton 64% / PET 34% / PU 2%). The structure of the fabric yarn was observed using the naked eye, a digital camera (FUJIFILM FINEPIX F770 EXR) and a field emission scanning electron microscope (FE-SEM, JEOL JSM-7000F).

2-4. Collection of information about the evolution of gym uniforms and everyday clothes

Various photographs were collected for studying the evolution of gym uniforms of elementary and junior high school, children's everyday clothes and adult’s everyday clothes. The clothes were investigated from the viewpoint of whether the fabric structure was woven or knitted. The “knit” means only “cut and sew” in this research. The woven and knitted fabrics

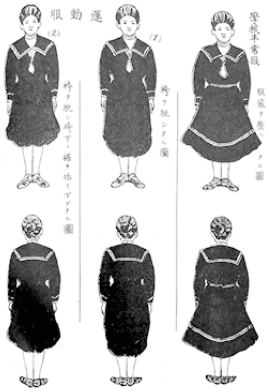
were differentiated from each other according to the manner in which they fit the body as well as their looseness, design of opening such as collar, sleeve, hem and so on. In addition, three people (age: from 58 years old to 65 years old) were asked questions.

3. Results and Discussions

3-1. Evolution of gym uniforms and everyday clothes

First, we describe the gym uniforms. The upper portion of gym uniforms for high school girls before the Second World War resembled the dress of a sailor, whereas the bottoms were a long bloomer which is like to a skirt with the hem turned upward[3] as shown in Figure 2 (a). This is said to be based on the girls' gym uniform proposed by Akuri Inokuchi, who was the principal of a girls' high school[4] as shown in Figure 2 (b).

(a) Girls' high school students（1936）.



(b) Gym uniforms proposed by Akuri Onokuchi.

Figure 2. Pictures of gym uniforms obtained from literatures. (a) is cited from ref. 3) and (b) is cited from ref. 4).

Figure 3 depicts some examples of elementary and junior high school gym uniforms since the 1960s. The photograph of 1965 (Figure 3 (a)) shows the usage of shirts for both boys as well as for girls and short pants for boys and bloomers (so-called "paper lamp bloomers") for girls[5]. Both the tops and bottoms were made from woven fabrics. The photograph of 1972 (Figure 3 (b)) shows that both girls and boys wore shirts made from knitted fabrics. For the bottoms, the boys wore short pants made from woven fabric, whereas the girls wore bloomers made from knitted fabric. The bloomers fit the contours of the body. These results suggest that knitted fabrics became rapidly popular for girls' uniform than for boys' uniform. The photograph of 1994 (Figure 3 (c)) shows both girls' and boys' shirts and short pants made from knitted fabrics.

(a) Elementary school students（1965）.

(b) Junior high school students（1972）.

(c) Elementary school students（1994）.

Figure 3. Pictures of gym uniforms obtained from photograph albums.

Further, the everyday clothing of children was studied. Since the beginning of the 1960s, majority of the boys and girls wore tops (shirts and blouses) and bottoms (pants and skirts) made from woven fabrics. Since around the end of 1960s, tops made from knitted fabrics, such as t-shirts, began to become popular[6] as shown in Figure 4 (a). There was no clear difference between boys or girls. For bottoms, boys and girls wear still pants and skirts, which are made of woven fabrics today.

(a) Children（1968）.

(b) Adult females（1948）.

Figure 4. Pictures of everyday clothing obtained from literatures. (a) is cited from ref. 6) and (b) is cited ref. 7).

Subsequently, the evolution of the everyday clothing of adult male and female was studied. After the war, male switched from the Japanese style "Kimono" to a western style of clothes quicker than female. On the contrast, female continued to wear Japanese style "Kimono"[7] as shown in Figure 4 (b). Clothing made from knitted fabrics, such as polo shirts for boys, began appearing around 1965; however, majority of the female still wore blouses and skirts that were made from woven fabrics. Since the 1970s, both male and female began to wear tops made from knitted fabrics, including t-shirts, polo shirts, sweat

shirts and hoodies. These results indicate that knitted fabrics became popular quickly for tops than for bottoms. These results mentioned above are summarized in Figure 5.

Figure 5 shows the quick popularization of knitted fabrics from the latter half of the 1960s to the beginning of the 1970s. In 1971, the casual wear became popular[8], which was the same time during which the popularity of the knitted fabrics skyrocketed. Currently, elastic woven clothings, such as skinny jeans and stretch slacks, are also sold. The popularity of casual wear and the usage of elastic fabric are also shown in Figure 5.

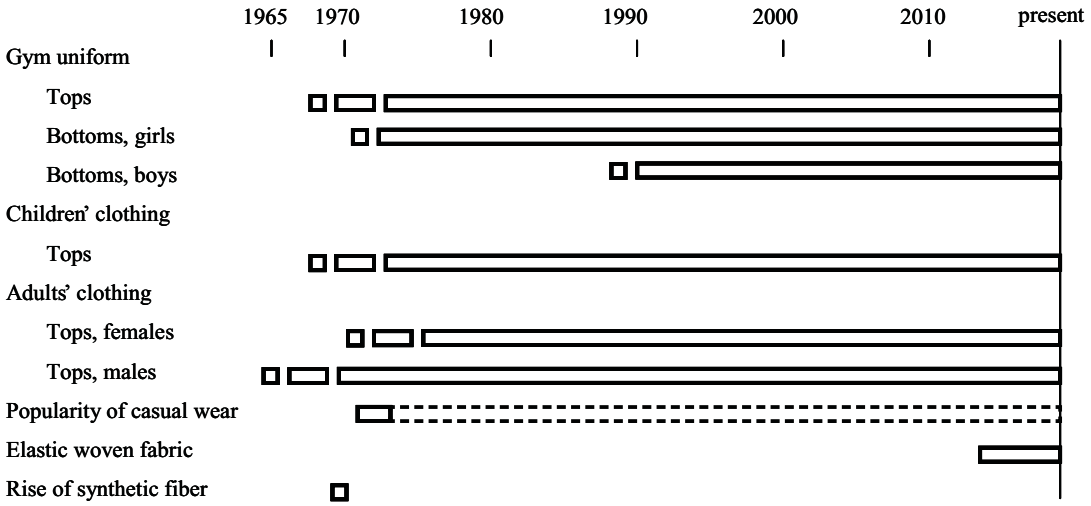


Figure 5. Evolution of gym uniform, children's and adults' clothing and related matters.

3-2. Mass production of fibers

A study of the production trend of fiber (yarn-based) in Japan revealed that the production of synthetic fibers overtook that of natural fibers in 1969[9]. During the 1960s, fibers were one of Japan's chief exports. Therefore, the ratio of natural fibers to synthetic fibers that were domestically produced does not differ significantly from that associated with the domestic consumption of clothing. This result is also shown in Figure 5. This Figure highlights that the time at which the knitted fabrics began to be extensively used for clothing by Japanese people almost coincided with the period at which the usage of synthetic fibers increased.

3-3. Comparison of the properties of woven and knitted fabrics

The tensile strength and breaking extension of various substrate samples were measured for comparing their properties. Figure 6 shows examples of load vs. elongation curves for three directions of a cotton woven fabric. The Figure shows that woven fabric is the hardest to stretch in the longitudinal direction, can be stretched in the lateral direction a little more than the longitudinal direction, and stretches best in the diagonal direction. The breaking strength of this fabric is almost the same longitudinally, laterally and diagonally. Figure 7 shows examples of load vs. elongation curves for a cotton knitted fabric. As compared with a woven fabric (Figure 6), the knitted fabric offers considerable elasticity as we know it from experience. It requires more force to tear the knitted fabric than that required to tear the woven fabric. These results indicate that the knitted fabric offer better elongation than that offered by the woven fabric in all the directions and that knitted fabric does not tend to tear owing to the deformation of the clothing. Therefore, we may assume that the knitted fabrics offer more ease of movement and comfort than those offered by the woven fabrics. The primary factor for the increased demand for knitted fabrics would be an increase in the "ease of movement" by people.

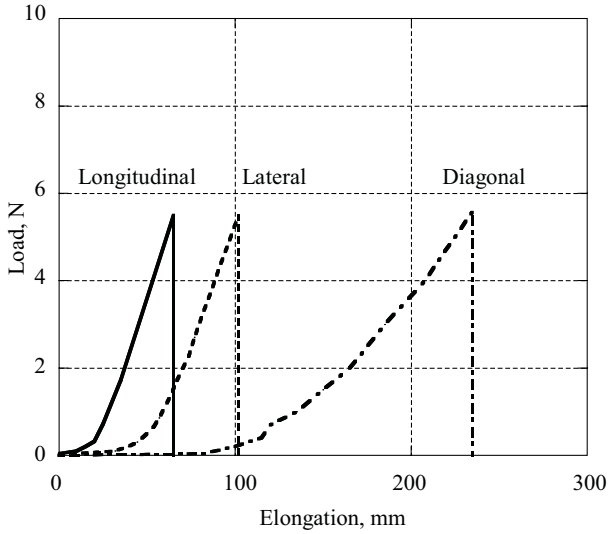


Figure 6. Load vs. elongation curves for a cotton woven fabric.

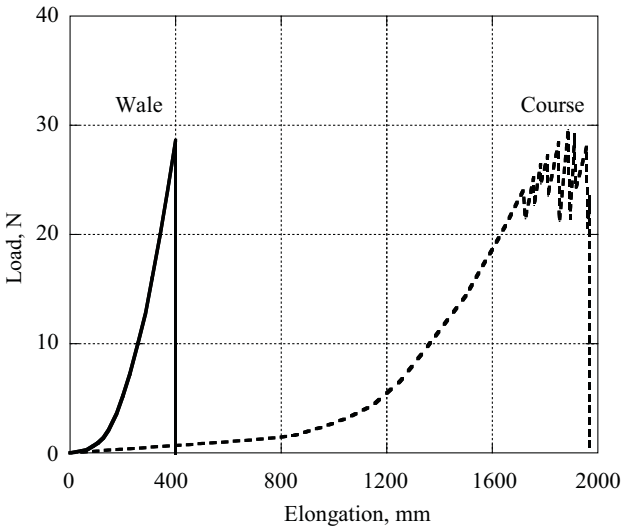


Figure 7. Load vs. elongation curves for a cotton knitted fabric.

3-4. Changes in the people's sentiment

One possible secondary factor behind the increased demand for knitted fabrics may be the “increasing status of knitted fabrics”. Japanese people considered that “knitted fabrics were not the kind of clothing that could be worn in a formal setting” in old days1). Then, the “increasing status of knitted fabrics” could be attributed to the fact that “knitted fabrics would also be suitable for making upper wear”. T-shirts, which were originally a form of underwear, were transformed into an upper garment in America, where they originated. Further, t-shirts achieved the status of an upper garment in Japan as well.

The third factor may be the “coexistence of design and function”. The clothes made from woven fabrics should exhibit considerable looseness to facilitate large movement and to impose restrictions on their design, such as paper lantern bloomers and knickerbockers. Thus, there seem to be a demand for “clothing that supported both ease of movement and good design with less looseness”.

The fourth factor may be the "break from hiding the body contours”. Clothing made from knitted fabrics tends to show the contours of the wearer’s body. This factor involves breaking away from Japanese traditional garment culture of “hiding the contours of the body” and replacing it with a “western culture that places the body’s contours on display”, thereby weakening the resistance to exposing the body contours.

As the fifth factor, high economic growth following the war led people to “money to spend” on stylish clothing. During the era of scarce supplies, people continued to wear clothes even if they were damaged owing to wear by repairing and reusing them for extended periods of time. The old woven fabrics were taken apart at the seams and were used to make other goods[10]. Knitted fabrics that had been industrially manufactured were hard to be reused for the common people. The “economic affluence” without reusing of clothing increased the popularity of knitted fabrics.

Because of the economic affluence, the cycle from purchase to disposal of one set of western clothes became shorter, giving birth to the idea of “style”. This probably could be attributed to the correlation of the five factors mentioned above and ultimately resulted in the sixth factor, “popularity of casual wear”, as depicted in Figure 5.

3-5. Comparison of the textile properties

Figure 8 shows examples of load vs. elongation curves for a PET knitted fabric. A comparison of this PET knitted fabric with the cotton knitted fabric in Figure 7 shows that the behaviors of both the fabrics are similar although cotton knitted fabric can be stretched more in the course direction. Figure 9 shows the residual strain ratio of the three types of substrate samples that are depicted in Figures 6 to 8. The stress in woven fabric is larger in the diagonal direction than in the longitudinal and lateral direction. The results of the residual strain rate of knitted fabrics differed according to the types of fibers. For the cotton

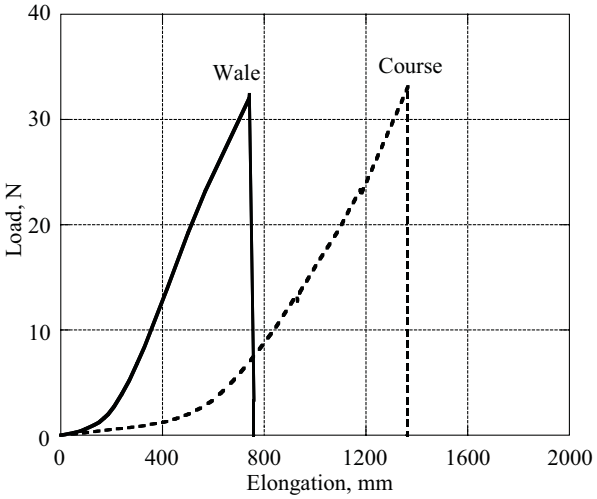


Figure 8. Load vs. elongation curves for a PET knitted fabric.

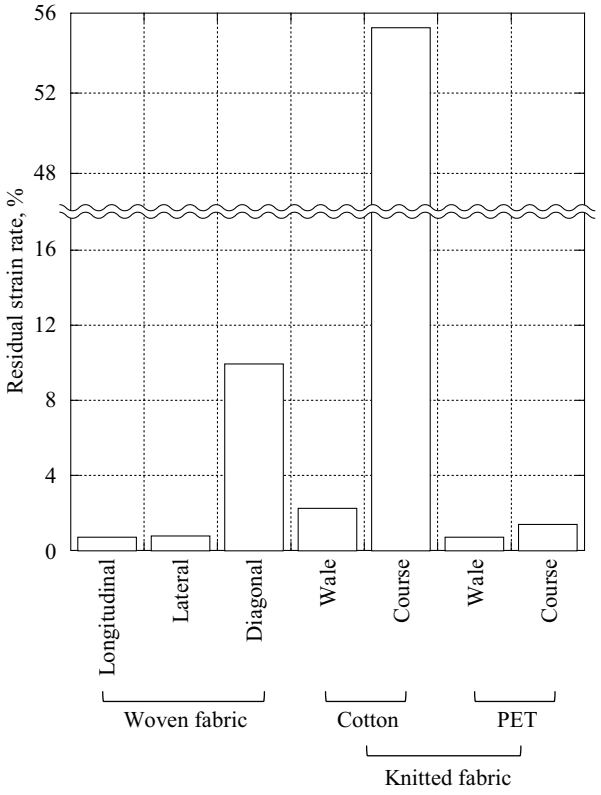


Figure 9. Residual strain rate of woven fabric and knitted fabrics of cotton and PET.

knitted fabric, the strain in the wale direction is considered to be slight; however, the strain is considerably large in the course direction. On the other hand, the strain for the PET knitted fabric is minor in both the directions.

Because PET fibers are filaments (long fibers) and exhibited a high degree of elasticity; therefore, strain does not tend to be produced as depicted in Figure 10 (a). On the contrast, cotton fibers are staples (short fibers), which are misplaced when they are stretched, causing the yarns to break as shown in Figure 10 (b). Even when the weight is removed, the fibers do not return to their original positions, resulting in the presence of residual strain in the fabric. Manufacturers have tended to switch away from cotton to synthetic fibers to be deformed in knitted fabrics. The increased usage of synthetic fibers is cited as the seventh factor to influence the knitted fabrics increased usage.

3-6. Structure of elastic woven fabrics

Recently, woven fabrics that offer considerable elasticity have been developed to make clothing such as skinny jeans. Here, the composition and structure of the slacks and skinny jeans that offer considerable elasticity were investigated. A study of the composition labels of garments revealed that slacks contained 6% PU and that skinny jeans contained 2% PU. Figure 11 shows photographs of a warp in black slacks. Figure 11 (a) shows that the yarn is separated into two bundles of black thin fibers and one white thick fiber. The white fiber was shorter than the black bundles of fibers and was extremely elastic. By considering the composition label, the white fiber is PU. The FE-SEM photographs (Figure 11 (b) and (c)) show that a thick fiber is in the center and is surrounded by thin fibers; this yarn is considered to be a core spun yarn in which a PU fiber exists. The structure of the weft in the slacks has the similarly structure with the warp. Then, the yarn of skinny jeans was investigated. The weft also exhibited the same structure as yarns of the slacks; but, the warp comprised only the same type of thin fibers and the highly elastic PU was not observed.

When two types of the pants were pulled in various directions, the slacks stretched in both the longitudinal and lateral directions, whereas the skinny jeans stretched only in the lateral direction. Therefore, the elastic woven fabrics were considered to be made using a core spun yarn with a PU core to provide elasticity. The structure of the yarn was observed in fine detail. In its usual state (not stretched), waves can be observed in the bundles of fibers as shown in Figure 11 (a). When the fabric is stretched, the PU fiber is elongated and the waves of other fibers are straightened. When the tension is relaxed, the PU fiber returns to its original length, and the bundles of other fibers return to their wave shape. This transformation gives the fabrics

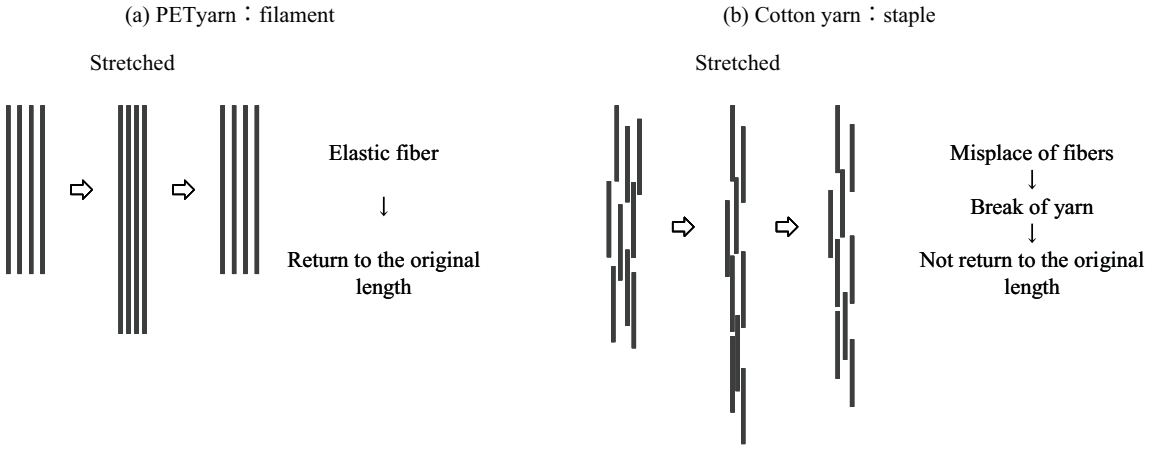


Figure 10. Changes of fibers in yarn. (a) PET and (b) cotton.

elasticity.

These results indicate that weaving fabrics that use core spun yarns with a PU core enables the fabrication of cloth with elastic properties while maintaining the characteristics of the fabric to retain its shape; this cloth can be used in formal wear and in designs that fit the body. The eighth factor associated with the increased demand for elastic materials would be the “change in the structure of the yarn”.

The eight factors mentioned above did not independently contribute to the popularity of elastic materials even though they contributed synergistically.

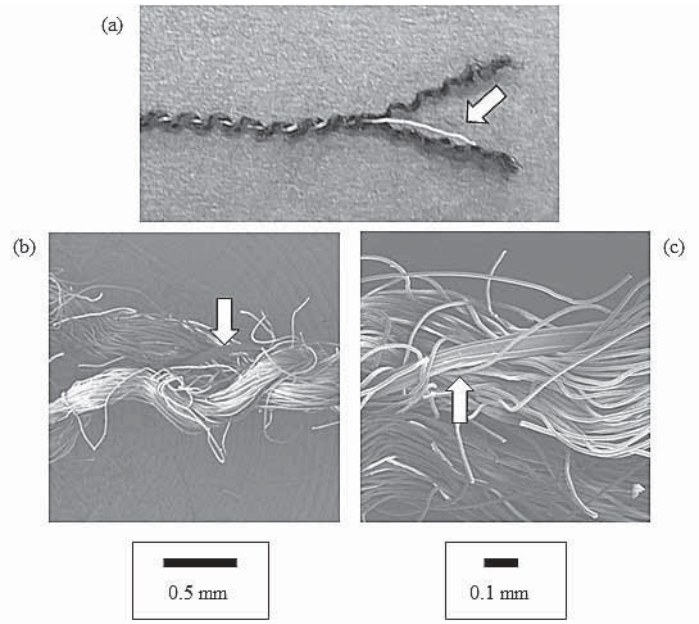


Figure 11. Pictures of a warp in slacks taken by digital camera (a) and FE-SEM (b) and (c). Arrows show polyurethane fiber.

4. Conclusion

The factors that were responsible for the increase in demand of elastic materials were investigated using various photographs and statistics related to the fiber production volume as well as the results of various experiments.

First, there have been changes in people’s feelings toward garments. The status of knitted fabrics improved, which enabled their acceptance for use in garments other than just underwear. Additionally, people began to demand garments in which design and functionality coexisted. People gradually changed their way of thinking from the old-fashioned culture of hiding the body contours to a culture that displays the body contours. This increased the popularity of casual wear. The abundance of the Japanese economy shortened the clothing cycle from purchase to disposal. This resulted in the concept of “fashion”. The rise of synthetic fibers resulted in the ability to produce knitted fabrics with a slight residual strain. The changes in the yarn structures owing to the development of core spun yarns resulted in the production of elastic woven fabrics, which provided clothing that maintained its shape and that exhibited considerable elasticity.

Funding

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