1. Introduction

Nanofibers are notable for their very small diameters, large surface area per unit mass and small pore size. These properties have given nanofibers a wide range of applications in areas, such as high performance filtration, battery separators, wound dressing, vascular grafts, enzyme immobilization, electrochemical sensing, composite materials, reinforcements, blood vessel engineering, and tissue engineering [1–4].

Fibers with diameters less than 1 μm can be formed using the conjugated spinning method, in which two polymer components are extruded together from a spinning die. Sea-island type conjugated spinning is a typical spinning method used for this purpose, in which many island fibers are arranged in a sea component that is later removed by extraction [5]. In detail, after weaving from the sea-island type yarn, the resulting fabric is exposed to solvent/alkali swelling or thermal/mechanical treatment, such that the two immiscible components separate, resulting in individual microfilaments. When the sea is dissolved with a certain solvent, the island polymer remains and forms the finest fibers. The number of islands, ratio of the island to sea components and cross-sectional shape of the ensuing microfilaments can be varied.


Appearance is an important property of textiles. In evaluating the fabric appearance, among other attributes, the luster should be taken into account [11]. The textile Institute [12] defined luster as follows: “Luster – The display of different intensities of light, reflected both specularly and diffusely from different parts of a surface exposed to the same incident light.” Methods for measuring the luster of fabrics are normally based on measurements of the reflectance. If a light beam impinges on a surface, it may be reflected specularly on a mirror surface, diffusely in varying intensities similar to that on a chalkboard surface, or as a combination of both. Therefore, one important component of the surface appearance is the
directional variation of the reflectance [13]. Shin et al. [14] reported a novel method for analyzing fabric images and estimated the luster. Their method was based on the distribution of the light reflection intensity of the fabric under the test and follows the goniophotometric principles. Hadjianfar and Semnani [15] used a fuzzy logic method to transform the numerical data to qualitative data to determine the luster index. Kanai et al. [16] attempted to define an index based on the distribution of the light reflection intensity on woven fabrics and examined its effectiveness in grading the principal factors, such as luster and surface roughness sensation governing fabric aesthetics.

An optical study of fabrics including luster has progressed steadily, but few studied on nanofilaments have been performed. Therefore, in this study, the optical properties of nanofilament fabrics based on two types of tests were investigated using untreated fabric and alkali-treated fabric up to the 600 nm level.

2. Experimental

2.1. Materials

In this study, nanofilament fabrics were woven with a yarn of sea-island type fibers, 600 nm in diameter, provided from Kolon Fashion Material, Inc. Table 1 shows the characteristics of the fabric. The warp yarn was same as the weft yarn, which is a draw textured yarn composed of PET as the island material and modified PET as the sea material. The density of the fabric was fixed to 88 counts/inch for the warp yarn and 62 counts/inch for the weft yarn.

The fabrics were soaked in a 0.5 M NaOH solution to remove the sea component under the following conditions. They were heated from room temperature to 100 °C at a rate of 2 °C/min, and maintained at that temperature after 30 minutes, and were then cooled to 80 °C at the same rate. After treatment, they were washed with hot and cold water to remove the NaOH solution stuck to the fiber surface. Finally, they were dried at 100 °C for 1 hour.

2.2. Optical Property Measurements

**Morphological Structure:** The surface structures of the fabrics were identified using field emission scanning electron microscope (Zeiss FE-SEM SUPRA25 and Raith Quantum Elphy, Germany), which operated on 5 kV.

**Pore Size Distribution:** A capillary flow porometer (CFP-1100A, USA) was employed to measure the pore size distribution. The fabric fully wetted with galwick (surface tension 16 dynes/cm) was mounted on the sample chamber and then the chamber was sealed. Pure nitrogen was allowed to flow into the chamber gradually. The pressure was increased continuously and the nitrogen permeation rate was measured until all pores of the fabric were empty of galwick, and the sample was considered dry. Nitrogen pressure and permeation flow rates through the dry sample were also recorded. Based on the nitrogen flow rates through the wet and dry sample, the pore size distribution was calculated [17].

**Luster:** To measure the luster of the fabrics in various directions, the incident light (Himax F-T6D) was fixed to 90°, which is perpendicular to the fabrics and the receiving angle was varied from 0° to 35° at 10° intervals, as shown in Figure 1. The diffused light was then measured in various degrees fixing the distance between the illuminometer (LX-1108) and fabrics to 12 cm.

**Anti-see Through Property:** The image acquisition system consisted of a charge coupled device (CCD) camera, LED lighting equipment, digital video recorder board and self-developed image converter program based on C++ 6.0, as

Table 1. Fabric characteristics

<table>
<thead>
<tr>
<th>Yarn</th>
<th>Density (counts/inch)</th>
<th>Composition</th>
<th>Sea-island ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp</td>
<td>P/DTY 50 De/12 filaments/4 Ply</td>
<td>Sea material : Modified PET</td>
<td>40:60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Island material : PET</td>
<td></td>
</tr>
<tr>
<td>Weft</td>
<td>P/DTY 50 De/12 filaments/4 Ply</td>
<td>Sea material : Modified PET</td>
<td>40:60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Island material : PET</td>
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</tbody>
</table>
shown in Figure 2, to evaluate the anti-see through properties by diffuse reflection due to the uneven surfaces of the samples. The CCD camera and LED light were fixed vertically to the fabric, which was laid down on a black circle (d=25 mm) and the lighting system was designed in such a way that the surrounding light is prevented from entering the photographic area. Consequently, the images were taken according to the distance change between a black circle and fabric at 10, 20, and 30 mm. The area of the images acquired by the CCD camera was 452×310 pixels (377 mm×258 mm). Analog images were converted to digital images using a digital video recorder board in a computer. The multi-level gray scale images were converted to binary images by turning each pixel on or off depending on whether its gray value falls at or above a given threshold or below it, respectively, using a self-developed program. Finally, the off areas in a binary image were calculated as the number of pixels per individually-identified object and then changed to the actual size for analyzing the anti-see through property.

3. Results and Discussion

Figure 3 shows the illuminance of the fabrics according to the position of the illuminometer. The illuminance of both the untreated fabric and alkali-treated fabric was lowest at 0° and 180° at which the incident light was perpendicular to the receiving position, and increased gradually towards 90°, which is a regular reflectance position, and 270°, at which a direct transmission occurred.

The illuminance of the alkali-treated fabric was higher than that of the untreated fabric except near 270°, at which direct transmission occurred. The surfaces of the alkali-treated fabric, which reflect the incident light into the illuminometer, are larger than the untreated fabric, because, as shown in Figure 4, the nanofilaments which comprise the inside of the microfibers were separated into each fine island component by dissolving the sea materials accompanying the increase on a specific surface.

In addition, the illuminance of the alkali-treated fabric was the largest near 270°. This is because much of the light was transmitted through the pores created by the removal of sea materials (Figure 4(d)). Figure 5 presents the pore size distribution of the fabrics, which also shows that the pore size of the alkali-treated fabric is much larger than the untreated fabric.

Evaluating the image actually some distance away from the fabric corresponds to required performance for the anti-see through property in actual life. Therefore, studies of the fabric attached to an object as well as the fabric which is away from an object will be needed. On the other hand, the experimental results suggest that nanofilament fabrics have poor anti-see through properties because much of the light is transmitted through the pores of the alkali-treated fabric near 270°. For further studies, an experiment according to the distance between the fabric and object was conducted.

The anti-see through test was designed to evaluate how
much the black circle is reflected after light passes through the fabric by digitalizing. In other words, the anti-see through property increases with decreasing sum of off pixels. As the distance between the fabric and black circle increases, the white background was observed increasingly darkly interfering with accurate measurements. In this study, what we want to measure for the anti-see through property is extent of the distinction between the object and background through the fabrics but the untreated fabric and alkali-treated fabric showed different background characteristics under the same condition because of the different diffused reflection features. Therefore, a normalizing process of the background is needed to minimize the influence of the background for identifying the object. For this purpose, the pixel values of the off area in the digitized images in accordance with the threshold value, which distinguishes on or off from the digitized images, were obtained, as shown in Figure 6.

In all cases, the graphs with similar curves show that the sum of the pixels of the background increased slightly with increasing threshold in the early stages, and increased significantly thereafter. Although the starting value of the threshold of the untreated fabric, where the sum of the pixels of the background become over 0, was higher than that of the alkali-treated fabric over the range of the graph, it showed reversal due to the large increase in untreated fabric. The excellent diffuse reflection from the surface of the alkali-treated fabric can cause this reversal. The threshold values that made the sum of background pixels the same (approximately 400) were determined by threshold analysis for each case and the acquired images were then converted.
to black-and-white images by applying these thresholds, as shown in Figure 7. Figure 7 shows as a black circle located farther away from the fabric, the extent of the reflection for the black circle through the fabric changed directly. Table 2 and Figure 8 present the pixel values of the black-and-white images.

According to Figure 8, the pixel values decreased with increasing distance between the black circle and the fabric in both alkali-treated fabric and untreated fabric. Generally, the pixel value of the untreated fabric is higher than that of the alkali-treated fabric, suggesting that the alkali-treated fabric has superior anti-see through properties to the untreated fabric. This is caused by increasing the specific surface area through a splitting microfilament into the nanofilaments by removal of the sea polymer. The anti-see through property of alkali-treated fabric was expected to be poor because of the large amount of light transmitted through the pores. Surprisingly, the anti-see through property improved due to the excellent diffuse reflection characteristics caused by an increase in the specific surface area.

4. Conclusion

This study examined the optical properties of the two types of fabrics woven with a yarn of sea-island type fibers, 600 nm in diameter.

Both the untreated fabric and alkali-treated fabric showed a similar illuminance pattern according to the location of the illuminometer, which was smallest at 0° and 180°, at which the incident light was perpendicular to the receiving position, and increased gradually towards 90°, which is the regular reflectance position, and 270°, at which direct transmission occurred. In addition, the illuminance of the alkali-treated fabric was larger than the untreated fabric except near 270°, at which much of the light was transmitted through the pores of the alkali-treated fabric.

The anti-see through property increased with increasing distance between the fabric and black circle in both the
alkali-treated fabric and untreated fabric, confirming that the anti-see through property of the alkali-treated fabric is superior to that of the untreated fabric. This was caused by the development of a reflective surface from microfilament splitting into nanofilaments even if the pores of the alkali-treated fabric made the anti-see through property poor.

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References

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