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Image Analysis of the Luster of Fabrics with Modified Cross-section Fibers

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Abstract: We have investigated the luster of modified cross-sectional fiber fabrics as one of the essential quality estimates for clothing development. We have confirmed an objective evaluation method, and have determined the experimental luster characteristics of modified cross-section fibers. The cross-section of the fibers in a fabric affects the appearance of a textile. We used the image analysis method to investigate the luster to determine the critical factors influencing the appearance of modified cross-section fiber fabrics. For similarly structured textiles in a component fabric, clear differences were observed in the fabric weave, density, percentage, and total area of blobs, which is image region. Color played a decisive role in the luster of the textiles, and luster was not significantly influenced by the modified cross-section fabric weave. In addition, the degree of luster did not increase in the order plain to twill to satin for modified cross-sectional fiber fabrics. All the split-type microfibers exhibited higher numerical luster values (percentage of pixels, and number and total area of blobs) than sea-island microfibers did. The degree of luster of the modified cross-sectional fiber fabrics was not high at specular reflection angles.

Keywords: Image analysis, Luster, Modified cross-section fiber, Microfiber

Introduction

Global fiber production is increasing continuously and, among the synthetic fibers, the consumption of polyester fiber has become particularly pronounced, especially with the development of new synthetic fiber. The characteristics of new synthetic fiber can be tailored to be silk-like, wool-like, or cotton-like. New synthetic fiber has unique properties that differ from natural fibers, and the development of this technology has changed the previous partial concepts about synthetic fibers. In making full use of the advanced technology afforded by polymer modification, advanced spinning technology, and the finishing of conjugated yarn, new synthetic fiber overcomes the limitations of synthetic polyester fibers [1,2], with basic aspects such as luster, color, and touch.

In particular, the luster of a fiber is closely related to its cross-sectional shape. The cross-sections of natural fibers are not circular, but possess various profiles, so that each natural fiber has unique characteristics in accordance with the shape of its cross-section. Recently, the physical properties of modified cross-section fibers, such as their luster, were adapted, and eco-fibers were produced using these modified cross-section fibers. These eco-fibers were produced with nylon modified cross-section fibers as the main material, and were tailored so that the maximum area was allowed for the attachment of microorganisms [3-5].

The most marked effect of modifying the cross-section of fibers is an improvement in luster. Other physical properties, such as the drapability required for polyester, can be improved on by using a light rayon (modified cross-section) made from filaments having rayon as their outer material and high stress, high shrinkage new synthetic fiber as their core yarn. The cross-sections of these fibers can have a Y-shape, a triangular shape, or another shape, so that the fibers can scatter light, and the circular hollow of a spinning nozzle can form special shapes that can confer on the synthetic fabrics a smooth touch or a quality like the luster of silk. The touch and luster of these fibers are superior to those of other synthetic fabrics, and these fibers have replaced fabrics traditionally used in Korean folk clothing that had previously been woven using only silk or artificial silk. This illustrates an advantage of these modified cross-section fibers: their ability to modify their luster to confer a silk-like elegance.

Recent reports have suggested that the cross-section influences both the external characteristics and the sensitivity of fabrics [6-8]. Recent research has focused on the luster of fabrics, emphasizing external characteristics [9-12]. As discussed above, the cross-section of a fabric exerts a significant influence on its external appearance, and modified cross-sections have more influence than circular cross-sections. However, there is almost no published data that effectively analyzes the luster and external appearance of modified cross-section fibers.

Therefore, we aimed to analyze quantitatively the luster of modified cross-section fibers in detail to provide a more effective analysis and observation of luster, which is the most important characteristic of modified cross-section fibers.

Experimental

Materials

The characteristics of fabrics used in this study are listed in Table 1. Samples 1, 3, and 6 are special materials having fabric cross-sections that are controlled during the spinning stage, as in Coolon® (Hyosung Co., Korea). These fibers are

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Table 1. Characteristics of the fabrics used

Sample no.	Fiber contents	Weave	Fabric count (threads/inch^2)	Yarn count	Thickness (mm)	Color
1	N19/P81	Twill	212 × 86	PF 75d/36f × N/P320d/144f	0.37	Dark Navy
2	N16/P84	Plain	210 × 75	PF 50d/72f × N/P 160d/72f	0.24	Bright Blue
3	P100	Twill	200 × 101	PF 75d/72f × PF150d/144f	0.30	Pale Blue
4	P100	Twill	220 × 90	PF 80d/96f × PF 81d/36f	0.24	White
5	P100	Plain	150 × 129	PF 75d/72f × PF 75d/72f	0.23	Beige
6	P100	Plain	104 × 90	PF 75d/72f × PF 75d/72f	0.14	Dark Blue
7	P100	Satin	240 × 104	PF 67d/36f × PF 81d/72f	0.21	Green
8	C100	Plain	37 × 29	C 464.4d × C 728.1d	0.49	Dark Blue
9	C / P	Twill	128 × 90	C 242d × PF 161d/72f	0.48	Navy

sweat absorbing and fast drying, and have a unique luster, in accordance their visual characteristics and differentiated cross-section at the surface of the yarns. Sample 9 was a combined yarn with a modified cross-section fiber weft mixed with cotton. Sample 7 was cotton, and was tested to form a comparison with the mixed modified cross-section fibers of Sample 9. Samples 1 and 2 contained sea island-type microfibers, and Samples 3 and 5 contained split-type microfibers. Fibers that were affected by Writing Effect could be observed, as well as moist suede microfibers from the dense, raised surface on ultra fine yarns.

Table 2. Viewing and illumination directions

Angle no.	γ_i	θ_i	θ_v	γ_v
1			0	180
2		30	30	180
3			45	180
4			0	180
5	0	45	30	180
6			45	180
7			0	180
8		60	30	180
9			45	180
10			0	225
11		30	30	225
12			45	225
13			0	225
14	45	45	30	225
15			45	225
16			0	225
17		60	30	225
18			45	225
19			0	270
20		30	30	270
21			45	270
22			0	270
23	90	45	30	270
24			45	270
25			0	270
26		60	30	270
27			45	270

Key: γ_i and γ_v: azimuthal angles of the illumination and viewing directions, respectively, θ_i and θ_v: polar angles of the illumination and viewing directions, respectively.

Image Acquisition and Processing

The image acquisition system consisted of a charge coupled device (CCD) camera, a data station, lighting equipment, and a zoom lens. The area of the images acquired by the CCD camera was 640 × 480 pixels. The images were digitalized using an analog to digital (A/D) converter employing frame-grabber electronics and saved in the data station. The images were saved as MS windows bitmap (.bmp) files. The optical angles measured during the experiments are shown in Table 2, and Figure 1 shows a schematic drawing of the measurement angles in three dimensions. The measurement distance between the sample and the light source was 10 cm. The illumination intensity was adjusted to 9,000 lux for a distance between the light source and the sample of 15 cm, which was the maximum value for the light source used. The focal distance between the camera and the sample was approximately 6 cm. A flat anodized plate was used as a standard plate placed below the samples to prevent the observations being influenced by

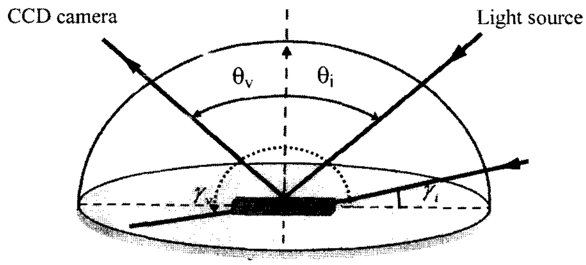


Figure 1. Definition of the angles used for the three-dimensional luster measurement.

Table 3. Features used during blob analysis

	Features	Descriptions
Blob	Percentage of blobs	Percentage of blobs in ROI.
	Numbers of blobs	Numbers of blobs in ROI.
	Total area	Sum of pixels for all the blobs.
	Mean area	Mean of pixels for all the blobs.
	Roughness	A measure of the roughness of a blob. (A smooth convex object, such as a circle or ellipse, has the minimum roughness = 1.0).
Pixel value	Sum of pixels	The sum of all pixel values for all angles.
	Mean pixel	The mean pixel value for all angles.
	Sum of square of pixels	The sum of the squares of each pixel value for all angles.

Key : ROI = region of interest.

the color from the bottom surface of the samples. We used the Global Lab image analysis software program (Data Translation, USA) to analyze the luster of the modified cross-section fibers, and to carry out analysis of the blobs, image regions, that facilitated the luster. Our blob analysis quantified the dimensions, direction, and average number of blobs in the acquired images. The reasons for conducting this analysis were to determine the quantity and the quality of the luster by visual inspection, and to determine how luster can be expressed quantitatively through enlarged fabric sections. A blob was defined as the size of a particle at a defined threshold, and the magnitude of the luster defined by the threshold of a detailed image. It was possible to generate various types of data related to the luster using these blobs. Key factors were selected among the many factors that could be analyzed using the blob image analysis program, and these were used to express the luster. The pixel, or picture element, was the smallest unit in the digital images. Each pixel denoted an intensity value in an image. The region of interest was defined as a region in the original image that an observer either selected, or was interested in. Table 3 shows the features of the data used to define the luster using our image analysis program.

Results and Discussion

The blob and pixel values of the samples obtained from the blob analysis are shown in Table 4. These data are average values of the luster obtained from the blob analysis of the samples pictured at the 27 points shown in Table 2. Samples 1 and 2 were fabrics that had similar nylon content, and had twill and plain weave structures, respectively. It was earlier noted that the degree of luster of commercial fabrics in relation to the weave increases from plain to twill to satin [11]. Therefore, we expected that Sample 1 would have a higher luster than Sample 2, as twill generally exhibits higher luster than plain weave. However, Sample 2 exhibited a higher luster. This was due not to the difference in luster of the different weaves but to the difference in color, as the color of Sample 2 was brighter than that of Sample 1.

Even though Samples 5 and 6 had similar components, weave, and densities, the differences in blob percentages and total areas were significant. This result demonstrates that the color of a fabric was the most critical factor for estimating the luster of samples with similar weaves, blob density, and material components. This result also indicates that the color of a fabric was the main influence on the luster of the fabric, even though the weave and structure of the fabrics were tailored to produce luster. From these results, it can be deduced that color was the most critical factor for estimating the luster of the fabrics rather than any microstructural characteristics of the modified cross-section microfiber and commercial fabrics.

Although Samples 6 and 8 had the same weave and color, Sample 6 showed higher values in percentage, number, and total area of blobs than Sample 8. In general, the structure of the synthetic fibers was smoother than that of the natural fibers, and the natural fibers mostly exhibited slight curvatures on their insides. Therefore, the synthetic fibers generated more specular reflections on their surfaces, so that they were more lustrous. For reflected light, a modified cross-section involves a more complicated reflection than for a simple circular cross-section, and so it was observed that the modified cross-section fibers generated more luster than the commercial fabrics of Samples 8 and 9. This illustrates that the filaments of synthetic fibers are more lustrous than cotton and natural fibers when both types of fiber have the same weave and color.

The cotton-containing samples, Samples 8 and 9 had plain and twill weaves, respectively, and thus, Sample 9 was more lustrous than Sample 8. This result supports previous research [11]. However, other results were identified from the modified cross-section fabrics in Samples 1-7. Sample 2 exhibited higher blob and pixel values than Sample 1. The split-type 100% polyester modified cross-section fiber of Sample 5 showed higher values than Sample 3 for all characteristics except number of blobs. Sample 7 (satin weave) showed lower values than Sample 4 (twill weave). The weaves of the modified cross-section fiber fabrics showed a lower effect on the luster than commercial fabric weaves did. This result suggests that modified cross-section fabrics (Samples 1-7) had a finer structure than the commercial fabrics (Samples 8 and 9). A basic principle of modified cross-section microfibers is that fabrics (nonwoven or pile) generally become smoother as the diameter, d, of the yarn becomes thinner. In theory, even for fibers of the same material, as the diameter of the fiber becomes thinner, the bend and twist of fibers with a circular cross-section becomes smoother, and can be expressed as an exponential function. Because of this softness, twisting or slipping of the microfibers is facilitated. This effect is caused by both the existence of microspaces and by the microstructure of the microfibers. In regards to the microspaces and the material microstructure, the reflection of light by the synthetic microfibers would be different from that of commercial fabrics because of the number of multifilamentary groups on the surfaces of these fibers. These have an effect on the textile properties such as a significant increase in surface area per weight; a small radius of curvature (related to the direction of the cross-section, luster, and color tone); a high length to diameter ratio; an enhanced external appearance; ease of bending; and the ability to redistribute concentrated stress. As the diameter of the fiber decreases, softness, luster, and sliding ability increase. In addition, as the surface area increases, the specific strength also improves.

Therefore, when yarn fibers are woven and knitted into fabrics or nonwoven fabrics, the external appearance and the feel of the fabrics can be differentiated by the density of fibers, the number of microspaces, and the number of fibers existing on the surface. Optimization of these characteristics can significantly improve the functionality of existing fibrous materials, and can also add new functionalities. It is considered that modified cross-section microfibers can be widely used as artificial suede, artificial leather, high-density waterproof fabrics, as silk-like materials, and as wiping cloths. Modified cross-sectional microfibers still have many undetermined properties and it is not known what types of function can be generated by making the fibers finer. This implies that modified cross-section microfibers have the potential for use in new applications that presently do not exist.

Samples 3 and 5 contained split-type modified cross-section microfibers, and they showed more luster than samples containing sea island-type microfibers, in terms of their percentage, number, and total area of blobs. Even though sea island-type microfibers usually produce thinner fibers than split-type microfibers, the sea island-type microfibers had a higher luster value than the split-type microfibers. This fact is considered to be the result of the mainly circular cross-sections of the sea island-type microfibers contrasting with the other types of cross-section found in the split-type microfibers. We confirmed this observation by measuring the roughness of the samples, with a low roughness value denoting a near-circular blob. As shown in the roughness values listed in Table 4, Samples 3 and 5, possessing split-type microfibers, had higher roughness values than Samples 1 and 2, which possessed sea island-type microfibers. The pixel values listed in Table 4 also illustrate the same tendency as found in the blob regions discussed above. Samples 3 and 5, possessing split-type microfibers, had a higher sum of pixels and mean pixel values than Samples 1 and 2, which possessed sea island-type microfibers.

Figure 2 shows the percentage of blobs versus angle for Samples 2, 4, 5, and 7. Sample 2 was a plain weave mixed nylon and polyester fabric. Samples 4, 5, and 7 had twill, plain, and satin polyester weaves, respectively. Sample 2, with the plain weave, showed a lower percentage of blob values for all angles than Samples 4 or 7, which had twill and satin weaves, respectively. The polyester plain weave Sample 5 exhibited a larger percentage of blobs than Sample

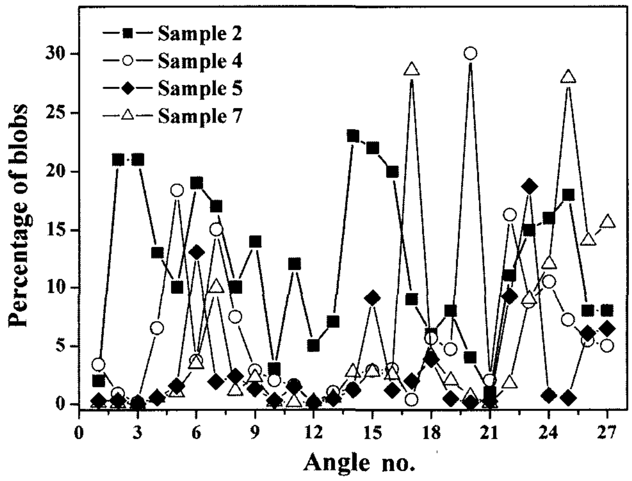


Figure 2. Percentage of blobs in Samples 2, 4, 5, and 7.

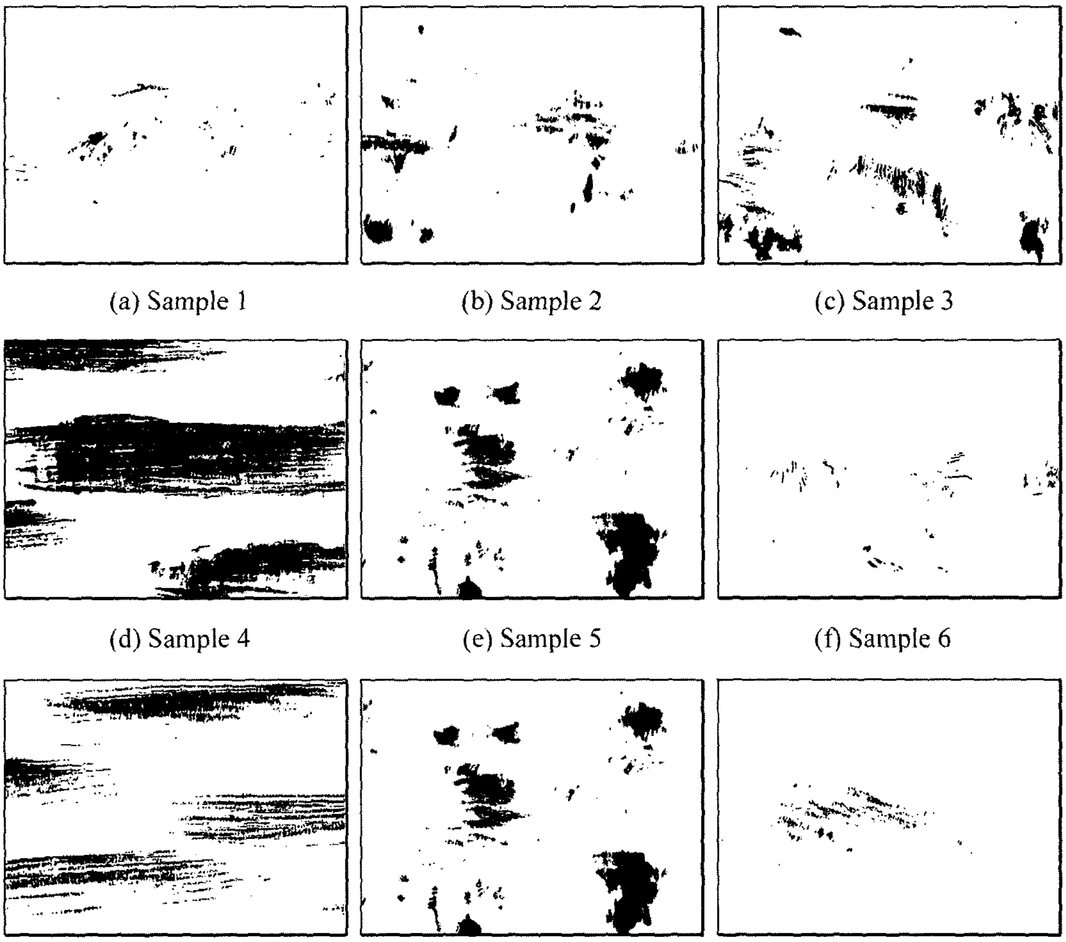
Table 4. Blob and pixel values of the samples

Sample no.	Blob					Pixel value		
	Percentage (%)	Numbers	Total area	Mean area	Roughness	Sum of pixels	Mean pixel	Sum of square of pixels
1	0.09	6.8	27.0	4.0	0.608	756	28	24,589
2	0.18	18.3	55.1	3.0	0.544	1,488	55	108,255
3	0.48	19.9	143.2	7.2	0.641	3722	143	1,064,963
4	6.43	9.3	1,929.9	206.8	0.456	44,962	2,141	193,174,668
5	3.09	17.9	926.4	51.7	0.703	25,013	926	72,507,897
6	0.09	10.9	26.7	2.5	0.557	693	27	23,349
7	5.48	10.5	1,642.7	157.0	0.535	42,710	1,643	218,558,681
8	0.06	16.1	16.6	1.0	0.808	430	17	8,096
9	0.08	12.4	24.4	2.0	0.787	561	24	15,898

2, which had the mixed nylon weave.

Angle numbers 2, 6, 11, 15, 20, and 24 were specular angles; the incident angle was the same as the receiving angle. The luster was higher for nonspecular angles. Previous research [13] has suggested that the percentage of blobs in commercial fabrics increases with the number of specular angles, as modified cross-section fiber fabrics do not produce as much luster with increasing specular angle as commercial fabrics. For modified cross-section fiber fabrics, the degree of reflection for all angles was not much different to that of commercial fabrics. This can be explained by modified cross-section fibers having good reflection properties caused by the structure of the cross-sections, less influenced by the specular angle than in commercial fabric. While modified cross-section structures also show differences in luster with changes in specula angle, we do not consider that these differences are caused by the different reflections at specular and other angles. Instead, the intensity of the luster becomes higher at angles slightly deviated from the specular angles. This result is similar to that seen in the luster of fabrics with delicate grains or hairs. Illuminated fabrics with fine grains or hairs demonstrate different types of luster from commercial fabrics that have flat and smooth surfaces due to their different surface structures [14,15]. As light generates diffused reflections due to the grains or hairs, the luster value increases at angles slightly deviated from specular angles because of the subtle reflection characteristics of the grains or hairs, rather than by any difference in the angular reflection properties. This phenomenon also occurred in our modified cross-sections. It is considered that while the structures of the fiber cross-sections are not superficially exposed, they do play a role in generating diffused reflections, like grains or hairs. Therefore, finer grains or hairs mirror the luster characteristics of our modified cross-section fibers.

Figure 3 shows threshold images of each sample taken at the point where $\gamma_i = 0$, $\theta_i = 45$, $\theta_v = 45$, $\gamma_v = 180$ and Figure 4 shows SEM of the cross-sectional shape of various fibers. Figures 3(a) and 3(b) show threshold images of sea island-type microfibers in Samples 1 and 2, and Figures 3(c) and 3(d) show threshold images of split-type microfibers in



(a) Sample 1 (b) Sample 2 (c) Sample 3

(d) Sample 4 (e) Sample 5 (f) Sample 6

(g) Sample 7 (h) Sample 8 (i) Sample 9

Figure 3. The threshold of Samples 1-9 for $\gamma_i = 0$, $\theta_i = 45$, $\theta_v = 45$, $\gamma_v = 180$.

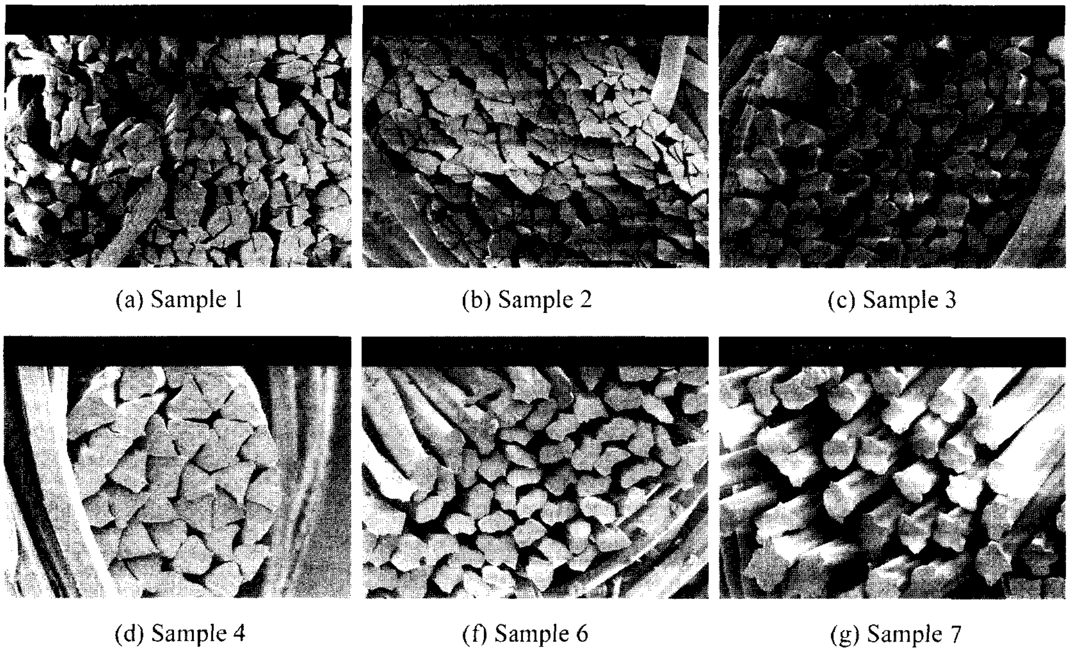


Fig. 4. SEM of the cross-sectional shape of various fibers.

Samples 3 and 5. As shown in the threshold images in Figure 3, spilt type microfibers had more luster than sea island-type microfibers. As explained above, because of the spinning of sea island-type microfibers into thin fibers, the look of the luster of sea island-type microfibers in Figure 3 was finer than split-type microfibers, even though the split-type microfibers showed more luster than sea island-type microfibers.

For samples 1, 2, 3, and 5, which were composed of components and weaves that were similar, Figures 3(a) and 3(c) show twill fabrics, and Figures 3(b) and 3(h) show plain fabrics, respectively. The plain fabrics showed larger regions of luster at the specular angles than the twill fabrics. Figure 3 shows a different trend from the previously mentioned normal increase in luster from plain to twill to satin. The degree of luster in commercial fabrics is influenced by the weave. On the other hand, in modified cross-section fibers, the degree of luster did not increase in the order plain to twill to satin, because the degree of luster in the modified cross-section fibers was also influenced by the weave, the planar structure of the fabrics, and the inner modified cross-section areas.

Samples 6 and 7 showed significant differences by weave. Sample 4 showed a substantial degree of luster compared with Sample 7, which had a satin weave. This is because Sample 4 was white, so that the predominance of the sample color had a significant influence on its luster properties.

Conclusions

The luster of modified cross-section fibers that influences the external appearance of fabrics was investigated using an image analysis technique to more effectively analyze luster as a property of modified cross-sectional fiber fabrics. This should satisfy the visual requirements for synthetic and high sensitivity fibers.

Although the weave and densities of the fabric samples studied were similar, they exhibited significant differences in the percentage and total area of blobs obtained from the image analysis, due to the different colors of the fabrics. This result suggests that color plays an important role in estimating the luster of fabrics. When compared with commercial fabrics, the degree of luster of the modified cross-section fiber fabrics did not increase in the order plain to twill to satin, which indicates that the weave of the modified cross-section fiber fabrics does not greatly affect the luster. The percentage, number, and total area of blobs in split-type microfiber fabrics were higher than those in sea island-type microfiber fabrics, indicating a higher degree of luster in split-type microfiber fabrics.

Compared with commercial fabrics, the degree of the luster at a given angle for the modified cross-section fibers did not increase significantly, and additionally, did not exhibit differences at all angles. This result suggests that the correct measuring angle is dependent on the modified cross-section of the fiber fabric, as some modified cross-sections can have good reflection characteristics.

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