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Hand-related Physical Properties and Luster Properties of Chitosan treated Cotton and Nylon Fabrics dyed with Natural Dyestuffs

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Abstract

Chitosan treatment of textile fabrics has been studied to improve fabric characteristics and functions. Natural dyestuffs have been more actively employed in environment-conscious finishing products. In this study, chitosan treated cotton and nylon fabrics were prepared for dyeing with a few natural dyestuffs. These were *Caesalpina sappan, Gardenia jasminoides*, and cochineal in the form of powder. Hand-related physical and mechanical properties and luster characteristics were examined using the KES-FB series instruments and a set of luster measuring equipment. The chitosan treatment seemed to be more effective in terms of increasing stiffness for cotton fabric. Since cotton fibers have more -OH groups in the molecules, they provide more linkage sites with the chitosan than the nylon 6 fibers do.

Key words: chitosan, cotton, luster, nylon, physical properties

I. Introduction

Chitin and its derivative, chitosan, have widely been manufactured and applied in diverse industries including textiles, pharmaceuticals, foods, etc. Chitosan has a number of $-NH_2$ groups in the molecular structure.[1,2] This is supposed to facilitate the absorption of dyestuffs as well as metallic ions.

The important aspects of a textile product are the hand and appearance of the product. These aspects are highly subjective and inter-related to each other. Quantification of fabric hand is complicated due to the wide range of responses that people experience when they touch and move a fabric in their hand. Since this property is influential in a consumer's decision-making process, much work has been conducted to quantify the factors comprising fabric hand. Objective measurement schemes have been devised through the use of integrated equipment called KES (Kawabata Evaluation System).[3]

Luster is one of the important characteristics of textile fabrics, especially for apparel use. Luster perception depends on the observation condition such as the incident beam intensity, angle, observer position, etc.

Dull surface materials such as chalk and blackboard exhibit diffuse reflection. In ideally diffuse material case, the 100% diffuse surfaces appear equally bright from all viewing angles since they reflect incoming light with equal intensity in all directions. In contrast, specular reflection can be observed on shiny surfaces. At the highlight, the shiny surface appears to be the color of incident light.

Textile products are comprised of fine fibers/yarns. These are mostly arranged in an orderly manner, warp/weft, wale/course, or MD/CD. Due to the directional properties, weave/knit structures, and texture details, the patterns of reflection or luster of textile products are vastly diverse. The reflection patterns are also dependent on the observing conditions including incident light and observation positions.

By incorporating chitosan treatment, the hand and physical properties, including luster, of the fabric may be modified. By adjusting the amount or the molecular weight of the chitosan, the hand of the fabric could be altered.

The purpose of this study is to investigate the effect of chitosan treatment and natural dyeing on the physical properties of fabrics at low stress level and the change of the fabric luster properties.

II. Experimentals

1. Fabric samples and chemicals

1) Fabric Specimens

Fabric specimens were white standard cotton and nylon 6 fabrics conforming to the KS K 0905 specifications for dyeing fastness test. They were purchased from the KATRI(Korea Apparel Testing and Research Institute).

2) Dyestuffs

Caesalpinia sappan, cochineal, and *Gardenia jasminoide*s dyestuffs were purchased from Mikwang International Co. in power form.

3) Mordants

Aluminum Potassium Sulfate ($AlK(SO_4)_2$, Duksan Pure Chemicals, Korea) was employed as an aluminum mordant.

4) Chitosan

Chitosan was produced in the laboratory with characteristics of Mn (number average molecular weight) 180,000, Mw(weight average molecular weight) 246,000, and polydispersity of 1.37. The readings were obtained using a GPC(Gel permeation chromatography). The degree of deaceytylation was determined as 100%.

2. Experimental procedures

1) Preparation of chitosan acetic acid solution

Chitosan (7gram) was dissolved in a solution of 1%(w/w) concentration acetic acid using a mechanical stirrer for 24hours resulting in a 0.7% concentration chitosan in acetic acid solution. Since the chitosan solution in acetic acid has a tendency of chain breakage due to the action of acetic acid, it was applied to the fabric immediately after the 24hour dissolution.

2) Chitosan treatment of fabric specimens

Specimen size of 30×30cm was prepared for chitosan treatment. The cut specimens were dipped in the prepared chitosan solution for 24 hours. The fabric specimens were treated using a mangle roller(Werner Mathis AG, Switzerland) with its pressure automatically adjusted. The wet pick up rates were 100% for cotton fabric and 40% for nylon 6 fabric. The fabric specimens, which picked-up chitosan solution, were left air-dried for 24hours. Then they were dyed in the subsequent dyeing process.

3) Pre-mordanting treatment of fabric specimens

Aluminum mordant was used in preparing mordanting solution with 1%(o.w.f) and liquor ratio 1:75. As the temperature of the mordanting solution reached 40~75˚C, fabric specimen was introduced to the bath, and the bath temperature was raised to reach 60˚C in 30 minutes. The specimen was mordanted for 60minutes in the bath at 60˚C and the bath was cooled down to 30˚C.

4) Dyeing of fabric specimen

Three kinds of powder dyestuffs were used to prepare for dyeing solutions as 10% (o.w.f.) and liquor ratio 1:70. After the water bath was heated to reach 40˚C, the dyestuff was introduced to the warm bath and dissolved. Three pieces of 30×30cm fabric specimen were dipped in the bath and the dyeing temperature of 60˚C was maintained for 60minutes. When the dyeing was finished the dye liquor was cooled down to 30˚C. The dyed specimens were then rinsed with enough water and air-dried for 12~15 hours.

5) Dyeing of fabrics at different dyeing interval

In order to investigate the effect of dye-uptake amount on the luster properties of dyed fabrics, samples were taken out from the dyeing bath at predefined dyeing intervals (5, 15, 25, and 60 minutes dyeing time at dyeing temperature of 60˚C)

6) Luster measurement

Since the luster properties of textile fabrics depend also on the observation conditions such

<Table 1> List of fabric specimens treated with chitosan and dyed/mordanted.

Sample	Dye	Mordant	Chitosan	
			untreated	treated
Cotton	Non-Dye	Non-Mordant	1	9
	Caesalpina sappan		2	10
	Gardenia jasminoides		3	11
	Cochineal		4	12
	Non-Dye	Al	5	13
	Caesalpina sappan		6	14
	Gardenia jasminoides		7	15
	Cochineal		8	16
Nylon	Non-Dye	Non-Mordant	17	25
	Caesalpina sappan		18	26
	Gardenia jasminoides		19	27
	Cochineal		20	28
	Non-Dye	Al	21	29
	Caesalpina sappan		22	30
	Gardenia jasminoides		23	31
	Cochineal		24	32

as incident light intensity, its angle, and viewing angle or position due to the complex surface nature of various textile fibers or yarns, it is important to determine the incident light and viewing conditions.

In this experiment, incident light angle was set at 45 degrees and the CCD (Charge Coupled Device) position/optical axis was normal to the fabric specimen. A CCD of 640×480 pixels was employed in this study. The CCD was connected to a frame grabber in a PC. The images were stored in the computer for image processing and analysis[4)] to examine the luster properties of the fabric specimens.

7) KES tests

The forces acting on a fabric specimen while rubbed or crumpled between fingers for subjective evaluation are shear, bending, compression and tensile forces. KES basically characterizes the fabric's response to these forces under low stress conditions.

In <Table 2>, summary of the KES parameters are given.

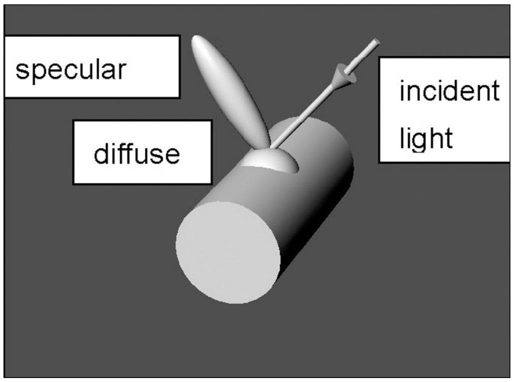
III. Results and Discussion

The effect of dye absorption on the fabric luster was examined using fabric specimens of differing amount of shades. The shade depth variation was achieved by varying dyeing time.

As the amount of dye absorption increased, the total area of luster objects on the fabric measured under specific illumination/observation condition using an image analysis program decreased.

<Table 2> List of KES parameters

parameter	description
EMT	percentage tensile elongation
WT	tensile energy or work done in tensile deformation represented by the area under the stress-strain curve
RT	tensile resilience which is the ratio of work recovered to the work done in tensile deformation
LT	the extent of non-linearity of the stress-strain curve. LT values below 1.0 indicate the stress-strain curve falls below the line that connects the origin and the peak point.
G	shear modulus
2HG	hysteresis width at the shear angle of 0.5°
B	bending rigidity
2HB	hysteresis width
t_0	fabric thickness at a very low pressure of 0.5 gf/cm^2
tm	fabric thickness at the maximum pressure of 50.0 gf/cm^2
WC	work done during the compression
RC	compressive resilience
LC	linearity of the compressive curve
EMC	compressibility which is the ratio of measured reduction in thickness to the original fabric thickness
MIU	coefficient of surface friction
MMD	mean deviation of coefficient of friction
SMD	index of geometrical surface roughness

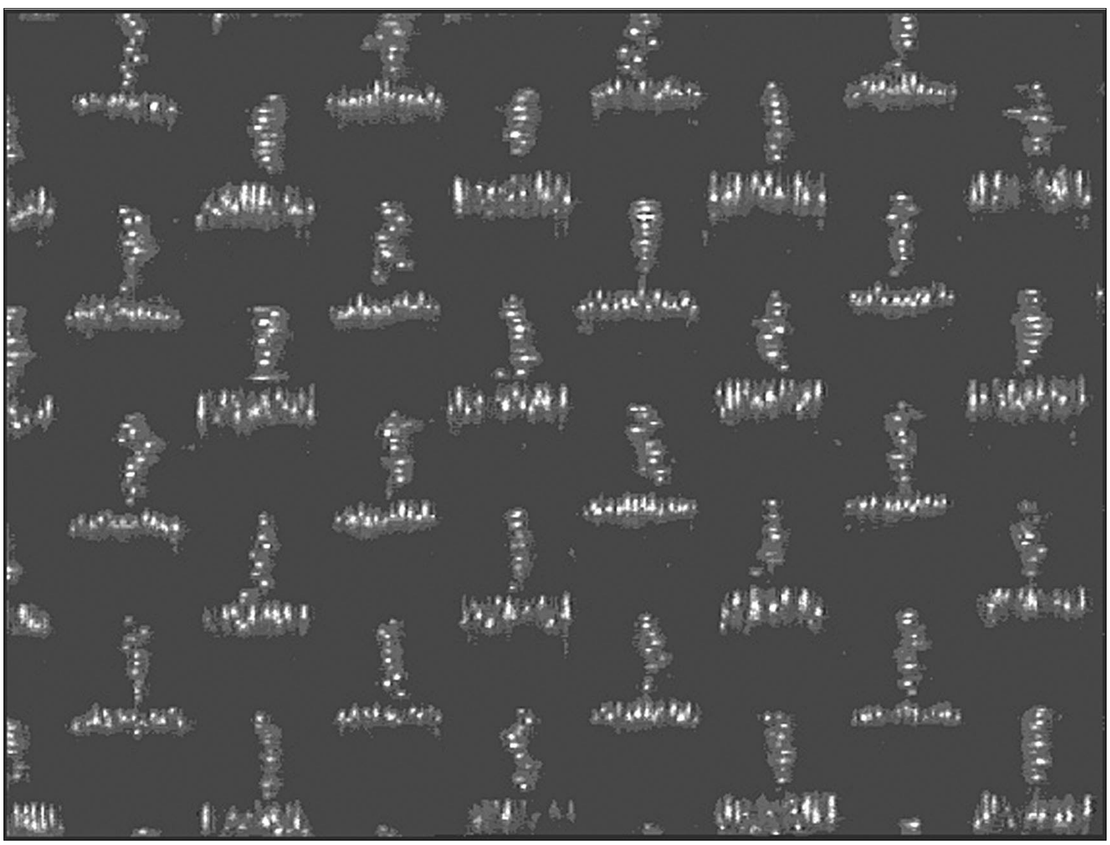


<Fig. 1> Schematic representation of reflection, specular and diffuse, from the surface of a cylindrical filament.

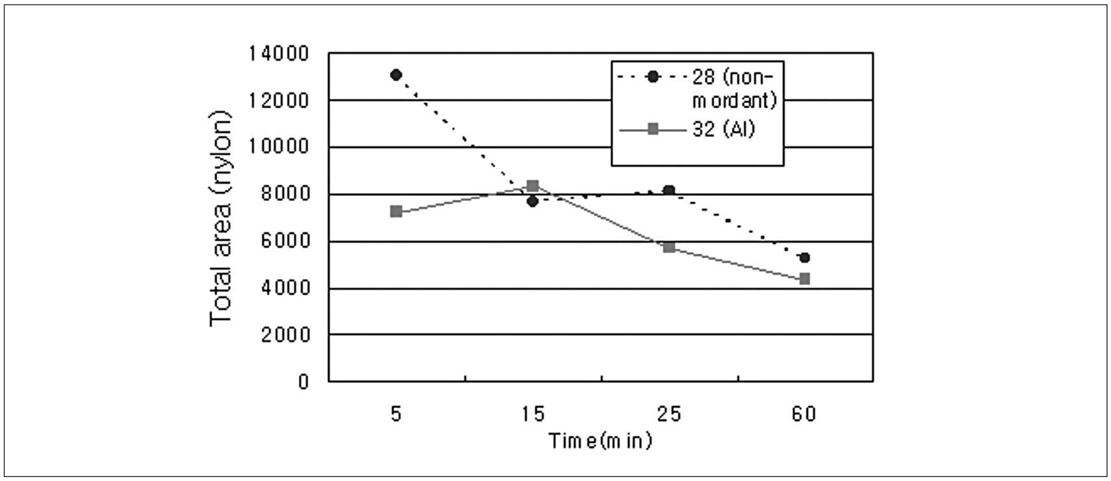
This is thought to be related to the dye-shade increase. This is illustrated in <Fig. 1>. Prominent reflection along the reflection path is due to the specular reflection component. Diffuse reflection is represented by the part of spherical shape on the cylindrical fiber. The diffuse reflection is mainly affected by the amount of dye molecules, or delustering agent inside the fiber matrix. The specular reflection seems to be affected by the diffuse reflection as a secondary factor.

<Fig. 2> shows the image of nylon fabric, dyed with cochineal, under the incident light 45°.

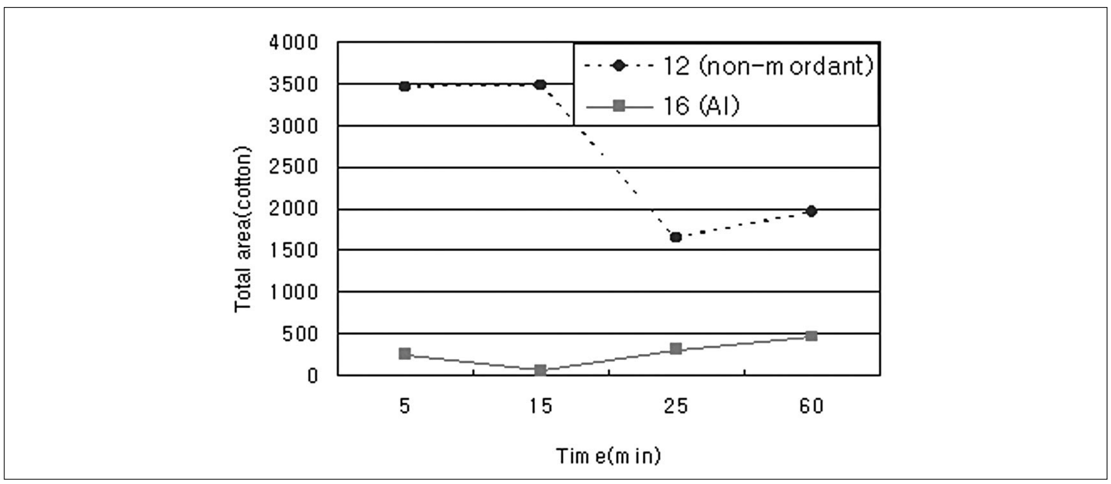
In order to investigate the effect of dye-uptake amount on the luster properties of dyed fabrics,



<Fig. 2 > A nylon fabric image acquired with incident light 45 (dyed with cochineal)



<Fig. 3> Sum of luster area of nylon 6 fabric dyed with cochineal.



<Fig. 4> Sum of luster area of cotton fabric dyed with cochineal.

samples were taken out of the dye-bath at some time interval. As the time of dyeing increased, the total of luster object area decreased. This seems to be highly related with the dye-uptake amount increase. Samples 28(non-mordanted) and 32(Al-mordanted) have shown similar effect in <Fig. 3>. Similar trend could be found with the cotton fabric samples treated with cochineal, with the exception for sample 16 which did not show any remarkable change in the total area of luster objects.<Fig. 4>

In case of cotton fabric, samples dyed with *Gardenia jasminoide*s has shown a tendency of increased luster object area as shown by the samples 3, 11, 7, and 15 compared to the cotton control fabric, even though there were some amount of dye-uptake. In case of nylon 6 fabric, however, *Gardenia jasminoide*s did not develop

<Table 3> Total area of luster objects.

Sample No.	Cotton	Sample No.	Nylon
1	39,282	17	33,137
2	26,891	18	12,200
3	51,269	19	18,467
4	36,691	20	8,537
5	32,440	21	25,147
6	5,144	22	10,234
7	45,774	23	26,695
8	21,549	24	6,882
9	14,540	25	31,171
10	9,576	26	13,341
11	42,614	27	20,330
12	1,961	28	5,242
13	51,342	29	27,114
14	156	30	12,475
15	43,117	31	26,839
16	459	32	4,356

the effect. In general, the increase could be attributed to minor rearrangement of yarn in the fabric structure or fiber morphological changes. Further investigation into this effect would be needed. It seems that the values of total luster objects area measurements are related to the dye depth in general except for some special cases such as described above.

The effect of chitosan treatment on the hand-related physical and mechanical properties was analyzed as follows. In the case of cotton fabric, B(bending rigidity) values were dramatically increased by almost 197% due to the chitosan treatment. In case of nylon 6 fabric, the increase (9% increase) was not so much remarkable compared to the case of cotton fabrics. In case of cotton fabric, G (shear rigidity) values were increased by 8% due to the chitosan treatment. In case of nylon 6 fabric, the increase was 4%. Since cotton fibers have more -OH groups in the molecules, they provide more linkage sites with the chitosan than the nylon 6 fibers do. The chitosan treatment seemed to be more effective in terms of increasing stiffness for cotton fabric. Shear rigidity of fabrics, in this study, did not change appreciably compared to the bending rigidity, suggesting that the chitosan solution has effectively permeated inside the yarn without remaining in-between the warp-weft crossing area.

The values of WT(Tensile Energy) for stiffer cotton fabrics seems to be lower than those of less stiffer cotton fabrics. As the chitosan effect on the yarns comprising cotton fabrics increased, the extension of the warp or filling yarns would be restricted. In turn, the tensile energy values of the chitosan treated fabrics were decreased as demonstrated by the samples, 9, 12, 13 and 16. These are chitosan treated cotton fabric specimen, chitosan treated cochineal dyed without mordant, chitosan treated and Al-mordanted without dyeing, and chitosan treated and Al-mordanted and cochineal-dyed, respectively.

It is interesting to note that the t_0(initial thickness) values and the WC(compressional energy) values of the cotton fabric specimens, 9 and 16 are the lowest of all the fabric specimens.

IV. Conclusions

Chitosan treated cotton and nylon fabrics were prepared for dyeing with a few natural dyestuffs. These were Caesalpina sappan, *Gardenia jasminoide*s, and cochineal in the form of powder. Hand-related physical and mechanical properties and luster characteristics were examined using the KES-FB series instruments

<Table 4> Physical/mechanical properties of treated fabrics measured using the KES.

Sample No.	B	2HB	G	WC	To	WT	SMD
1	0.0492	0.0616	0.920	0.146	0.466	9.770	5.467
2	0.0459	0.0580	1.000	0.153	0.464	18.250	3.950
3	0.0442	0.0562	1.025	0.158	0.479	16.900	5.413
4	0.0437	0.0605	1.050	0.252	0.557	18.500	3.575
5	0.0502	0.0662	1.135	0.138	0.483	15.150	4.791
6	0.0494	0.0620	1.115	0.147	0.491	19.130	5.645
7	0.0431	0.0553	0.980	0.135	0.457	16.520	5.467
8	0.0464	0.0620	1.005	0.138	0.566	18.100	5.767
9	0.4011	0.2983	1.270	0.123	0.413	13.430	5.359
10	0.0835	0.0762	1.175	0.147	0.461	17.250	5.484
11	0.0632	0.0603	1.035	0.147	0.444	17.730	5.542
12	0.1182	0.0847	1.195	0.178	0.479	16.700	4.886
13	0.1758	0.1156	0.920	0.137	0.447	15.450	5.052
14	0.0795	0.0637	1.210	0.150	0.457	18.000	5.061
15	0.0741	0.0640	1.000	0.161	0.464	16.200	5.125
16	0.1112	0.0715	1.085	0.129	0.417	15.750	5.156
17	0.0699	0.0334	0.485	0.022	0.129	7.850	2.395
18	0.0639	0.0215	0.775	0.025	0.142	5.780	3.992
19	0.0536	0.0246	0.575	0.022	0.142	7.450	2.581
20	0.0588	0.0258	0.645	0.019	0.132	7.000	3.418
21	0.0569	0.0236	0.480	0.024	0.144	7.500	3.069
22	0.0550	0.0154	0.495	0.059	0.188	5.630	4.546
23	0.0439	0.0207	0.490	0.022	0.144	7.550	3.799
24	0.0560	0.0250	0.700	0.022	0.132	6.320	3.372
25	0.0482	0.0215	0.525	0.021	0.127	7.480	3.479
26	0.0588	0.0194	0.595	0.024	0.134	5.650	2.881
27	0.0559	0.0254	0.630	0.036	0.171	7.930	3.731
28	0.0508	0.0238	0.495	0.024	0.137	7.750	3.448
29	0.1310	0.0427	1.065	0.021	0.137	8.100	3.733
30	0.0585	0.0192	0.485	0.024	0.144	5.650	4.077
31	0.0448	0.0202	0.470	0.027	0.156	7.600	4.097
32	0.0522	0.0216	0.545	0.026	0.146	7.380	2.681

and a set of luster measuring equipment. As the time of dyeing increased, the total of luster object area decreased. This seems to be highly related with the dye-uptake amount increase. The chitosan treatment seemed to be more effective in terms of increasing stiffness for cotton fabric. Since cotton fibers have more -OH groups in the molecules, they provide more linkage sites with the chitosan than the nylon 6 fibers do.

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