

Use of a Biomaterial as a Thickener for Textile Ink-Jet Printing

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ABSTRACT: The feasibility of using chitosan as a thickener in the pretreatment print paste for textile ink-jet printing was explored. An orthogonal analysis was used to determine the optimum conditions for using chitosan as a thickener in the pretreatment print paste and the effects of different process factors for achieving the best color yield in textile ink-jet printing. With the help of the orthogonal analysis, the importance of different process factors was found to be in the order of (1) the amount of urea used, (2) the amount of chitosan used, (3) the amount of sodium bicarbonate used, and (4) the steaming time. On the basis of the results of the orthogonal analysis, the optimum conditions for using chitosan as a thickener for the pretreatment print paste were concluded to be 40 mL of chitosan, 10 g of urea, 8 g of sodium bicarbonate, and 5 min of steaming. According to an analysis of the results of different color fastness tests, chitosan could principally work as

a pretreatment print paste thickener. However, the final color yield obtained from chitosan-containing cotton fabrics depended greatly on the stage of the chitosan application. Nevertheless, the color fastness properties and the outline sharpness of the prints of cotton fabric were greatly improved by the chitosan treatment. A two-bath chitosan treatment was developed to separate the chitosan from sodium bicarbonate and urea before it was padded onto the fabric surface to minimize the neutralization effect. On the basis of the results for the highest color yield obtained on the cotton fabric, it was confirmed that the two-bath chitosan treatment was successfully developed. In addition, chitosan could impart higher antibacterial properties with a slight reduction in the tensile strength of the cotton fabric. © 2007 Wiley Periodicals, Inc. *J Appl Polym Sci* 107: 1057–1065, 2008

Key words: biomaterials; surface; fibers

INTRODUCTION

In recent years, there has been increasing interest in the application of ink-jet printing in the textile market. The technique of ink-jet printing offers benefits such as speed, flexibility, creativity, cleanliness, competitiveness, and ecofriendliness.^{1–3} Recently, the production process of ink-jet printing for cotton fabric has been mainly focused on reactive dyes,⁴ but the application method is totally different from the conventional printing process.^{5,6} Because of the purity and specific conductivity requirements of ink-jet printing,^{5–7} none of the conventional printing chemicals, such as alkalis, urea, and sodium alginate (as a thickener), can be directly incorporated into the ink formulations.

Currently, sodium alginate is an important thickener commonly used for preparing the pretreatment print paste for ink-jet printing because of its ready solubility and excellent stability even after high-temperature fixation treatments.⁸ Similar to sodium alginate, chitosan is also widely used as a novel bio-

material. As natural polymers, sodium alginate and chitosan are biocompatible, biodegradable, and nontoxic.⁹ Previous research has reported that chitosan can be applied to different textile areas; for example, chitosan has been used in conventional textile printing to improve the dye uptake and color fastness.¹⁰ However, during the preparation of chitosan, acetic acid is used; a neutralization reaction may occur between the acid in the chitosan solution and the alkali, that is, sodium bicarbonate, in the pretreatment print paste. Therefore, the aims of this article are to (1) study the effectiveness of chitosan and its feasibility as a replacement for sodium alginate as a thickener in the pretreatment process for ink-jet printing and (2) propose a method to minimize the neutralization effect between the chitosan solution and sodium bicarbonate.

EXPERIMENTAL

Fabric

One hundred percent singed, desized, scoured, bleached, unmercerized plain-weave cotton fabric (136 g/m²) with 133 ends per inch (40 s) and 72 picks per inch (40 s) was used in this study.

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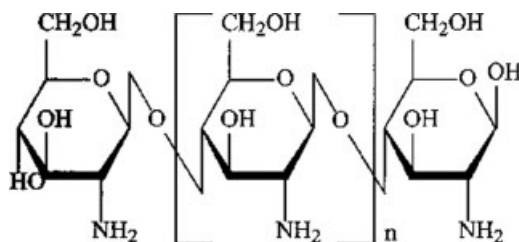


Figure 1 Chemical composition of chitosan.

Preparation of the pretreatment print paste

Unless otherwise stated, all chemicals used were analytical-reagent-grade. Chitosan ($R-NH_2$) in a solid form was supplied by Sigma Co. (St. Louis, MO), and the chemical composition is shown in Figure 1. A stock chitosan solution with a medium viscosity (~ 150 mPa s) was prepared through the complete dissolution of 5 g of chitosan into 500 mL of 10% acetic acid with constant stirring. The stock solution was then filtered to remove any suspended impurities. The amount of chitosan used in the pretreatment print paste was measured directly from the stock chitosan solution. Various amounts of urea and sodium bicarbonate were also added to the pretreatment print paste. To study the effects of individual parameters on each color, an $L_9(3)^4$ orthogonal analysis was adopted, and the experimental arrangements are shown in Tables I and II. Different pretreatment print pastes were prepared (viscosity ~ 300 mPa s) with respect to the amounts mentioned in Table II and made up to the final weight of 150 g with deionized water. Those pretreatment print pastes, prepared in accordance with Tables I and II, were termed *one-bath chitosan treatment*. In addition, a control pretreatment print paste (viscosity = 4200 mPa s) was prepared that contained 150 g of sodium alginate (this amount was obtained from a stock sodium alginate solution through the dissolution of 50 g of sodium alginate in 950 mL of deionized water), 10 g of urea, and 8 g of sodium bicarbonate.⁸

Fabric pretreatment

The pretreatment print paste was padded to the fabric with a padding machine (Labortex Co., Ltd., Taiwan) with a pressure of 2.6 kg/m² and a padding speed of 2.5 rpm to give a final wet pickup of 80%. The one-bath chitosan treatment fabrics were completely dried in an oven at 80°C and then cured at 170°C for 1.5 min, whereas the control fabric was completely dried in the oven at 80°C. All the pretreated fabrics were conditioned at 20°C with a relative humidity of 65% for 24 h before ink-jet printing.

TABLE I
Factors and Levels Used in the Orthogonal Analysis

Factor level	Pretreatment print paste gradient			Posttreatment steaming time (min)
	Chitosan (mL)	Urea (g)	Sodium bicarbonate (g)	
I	15	5	2	3
II	25	10	4	5
III	40	20	8	10

Two-bath chitosan treatment

To minimize the effect of neutralization during the mixing of the chitosan solution and sodium bicarbonate in the pretreatment print paste preparation process, a two-bath chitosan treatment was proposed that included (1) an acid bath and (2) an alkali bath. In the acid bath, the fabrics were first soaked for 2–3 min in the stock chitosan solution and then padded uniformly on the fabric with a padding machine until a wet pickup of 80% was achieved. Second, the padded fabrics were cured at 170°C for 1.5 min. The fabrics were then washed with deionized water for 5 min after curing. The acid-bath-treated fabrics were then dried completely in an oven at 80°C and were further conditioned at 20°C with a relative humidity of 65% for 24 h before the treatment with an alkali bath.

After the chitosan treatment with the acid bath, the fabrics were treated with an alkali bath. In the alkali bath, a pretreatment paste containing 10 g of urea and 8 g of sodium bicarbonate in 150 g of deionized water was prepared, and this pretreatment paste was padded onto the chitosan-pretreated fabrics by means of a padding machine until a wet pickup of 80% was achieved. The two-bath chitosan treatment fabrics were then dried completely in an oven at 80°C and subsequently conditioned at 20°C with a relative humidity of 65% for 24 h before ink-jet printing.

TABLE II
Experimental Arrangement

Trial	Pretreatment print paste gradient			Posttreatment steaming time
	Chitosan	Urea	Sodium bicarbonate	
1	I	I	I	I
2	I	II	II	II
3	I	III	III	III
4	II	I	II	III
5	II	II	III	I
6	II	III	I	II
7	III	I	III	II
8	III	II	I	III
9	III	III	II	I

Ink-jet printing and posttreatment

An ink-jet printer (Mimaki Tx2-1600, Mimaki Engineering Co., Ltd., Nagano, Japan) was used that was a piezoelectric drop-on-demand ink-jet printing machine. Four commercially available reactive ink-jet inks (cyan, magenta, yellow, and black), supplied by Tian Li Modern Office Articles Co., Ltd. (Shanghai, China), were used directly without further purification.

A square pattern of 80 mm × 80 mm was printed for each color at 360 dpi × 360 dpi for easy comparison. After ink-jet printing, the printed fabrics were air-dried and then steamed at 110°C for 5 min for color fixation. The steamed fabrics were finally washed in a nonionic detergent (10 g/L) until all the unreacted reactive inks and chemicals were removed.

Color yield measurement

The printed fabrics were conditioned at 20°C with a relative humidity of 65% for 24 h before the color yield measurements with a Macbeth Colour Eye 7000A spectrophotometer (Victoria, Australia). The measurements were taken under a speculum excluded with a large aperture. The fabric was folded two times to ensure opacity and then measured twice; that is, the measurement was conducted in both the warp and weft directions. The measured results were finally averaged.

The color yield, expressed as a K/S value (where K is the absorption coefficient depending on the concentration of the colorant and S is the scattering coefficient caused by the colored substrate), ranging from a wavelength of 400 to 700 nm with 20-nm intervals within the visible spectrum was calculated. The K/S values were summed according to eq. (1). The higher the K/S (sum) value was, the greater the dye uptake was, resulting in a better color yield:

$$K/S = (1 - R^2)/2R \quad (1)$$

where R is the reflectance of the colored sample.

Color fastness of the fabrics

The colorfastness of the ink-jet-printed fabrics to washing and crocking were assessed by AATCC test method 61-2001 and AATCC test method 8-2001, respectively.

Surface appearance of the fabrics

The surface appearance of the fabrics was observed with a JEOL (Tokyo, Japan) JSM-6335F field emission scanning electron microscope with a magnification of 3000×.

Outline sharpness measurement

To compare the outline sharpness of the prints, the width of the printed pattern in both the warp and weft directions was measured with a Nikon Optiplot-Pol (New York, USA) optical light microscope with a magnification of 400×.

Determination of the tensile strength of the printed fabrics

The tensile properties of the ink-jet-printed fabrics were measured according to ASTM D 5034-1995 with an Instron (Canton, MA) 4411 tensile tester.

Test of the antibacterial effects

The antibacterial effects of the ink-jet-printed fabrics were quantitatively evaluated by AATCC test method 100-1993. The quantitative antibacterial evaluation is given by eq. (2):

$$R(\%) = (B - AB)/B \times 100 \quad (2)$$

where R is the reduction ratio, A is the number of bacteria recovered from the inoculated treated test specimen swatches in a jar incubated over the desired contact period, and B is the number of bacteria recovered from the inoculated treated test specimen swatches in the jar immediately after inoculation.

RESULTS AND DISCUSSION

Optimum condition analysis

The optimum conditions of the pretreatment print paste containing chitosan together with the steaming time were determined by means of an orthogonal analysis, and the results are summarized in Table III.

Effect of chitosan on the pretreatment print paste (one-bath chitosan treatment)

Figure 2 clearly shows that black had the highest color yield, followed by cyan, magenta, and yellow. When the amount of chitosan used in the pretreatment print paste was increased, the color yields of the printed fabrics were enhanced correspondingly. This confirmed that chitosan could serve the function of increasing the color yield of ink-jet printing. This behavior is probably due to the fact that the amino groups present in the chitosan took up protons from the slightly acidic dye bath to form the $-\text{NH}_3^+$ groups. These $-\text{NH}_3^+$ groups, being electropositive in nature, could facilitate the transfer of the negatively charged dye anions from the bath onto the fabric, thereby improving color fixation.^{11,12}

TABLE III
Orthogonal Analysis Table for the Optimization of Each Color

Trial	Pretreatment print paste gradient			Posttreatment steaming time	Color yield (K/S)			
	Chitosan	Urea	Sodium bicarbonate		Cyan	Magenta	Yellow	Black
1	I	I	I	I	62.93	40.82	35.62	114.76
2	I	II	II	II	70.27	52.89	47.38	132.75
3	I	III	III	III	56.08	32.04	27.77	91.30
4	II	I	II	III	65.22	45.77	44.84	130.25
5	II	II	III	I	76.93	55.05	55.82	152.57
6	II	III	I	II	57.42	35.14	35.86	95.46
7	III	I	III	II	77.42	71.28	58.02	174.17
8	III	II	I	III	76.62	54.07	49.09	134.06
9	III	III	II	I	64.95	41.92	42.82	117.04
Cyan		Σ I	189.28	205.57		196.97		204.81
		Σ II	199.57	223.82		200.44		205.11
		Σ III	218.99	178.45		210.43		197.92
		Difference	29.71	45.37		13.46		7.19
Magenta		Σ I	125.75	157.87		130.03		137.79
		Σ II	135.96	162.01		140.58		159.31
		Σ III	167.27	109.10		158.37		131.88
		Difference	41.52	52.91		28.34		27.43
Yellow		Σ I	110.77	138.48		120.57		134.26
		Σ II	136.52	152.29		135.04		141.26
		Σ III	149.93	106.45		141.61		121.70
		Difference	39.16	45.84		21.04		19.56
Black		Σ I	338.81	419.18		344.28		384.37
		Σ II	378.28	419.38		380.04		402.38
		Σ III	425.27	303.80		418.04		355.61
		Difference	86.46	115.58		73.76		46.77

The bolded numbers show the greatest values for the levels of different factors used.

Furthermore, Figure 2 also shows the color yields of these four different colors under the influence of various amounts of chitosan used in the pretreatment print paste. The maximum color yield was achieved when 40 mL of chitosan was used in the pretreatment print paste.

Effect of sodium bicarbonate on the pretreatment print paste

Figure 3 shows that black had the highest color yield, followed by cyan, magenta, and yellow. However, the effects of sodium bicarbonate on the pretreatment print paste in cyan, magenta, and yellow were not significant in comparison with black. Generally, when the amount of sodium bicarbonate used in the pretreatment print paste was increased, the color yields of the printed fabrics were increased.

Similarly to its use in dyeing processes, an alkali is used in printing processes for the color development of all shades. The presence of an alkali is essential for producing the ionization of accessible cellulose hydroxyl groups that can then react with the reacting groups of reactive dyes in the fixation stages. Sodium bicarbonate has been the preferred

alkali because of its relatively low cost, and it can give sufficient pretreatment print paste stability with most of the reactive dyes available in the market. During steaming, sodium bicarbonate loses carbon dioxide and increases the ionization of cellulose, which thus promotes the dye-fiber interaction in the fixation stage.

Effect of urea on the pretreatment print paste

Figure 4 demonstrates the color yield of different colors under the influence of various amounts of

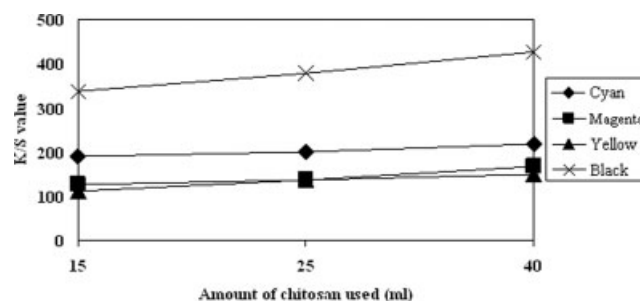


Figure 2 Effect of the amount of chitosan on the color yield of different colors.

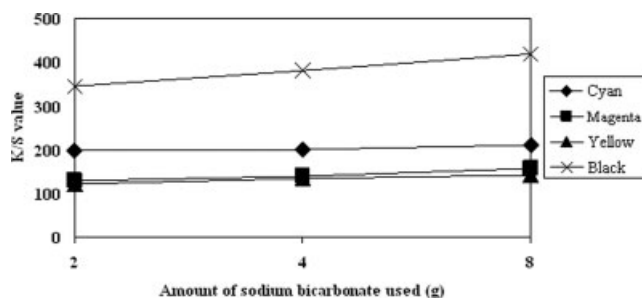


Figure 3 Effect of the amount of sodium bicarbonate on the color yield of different colors.

urea used in the pretreatment print paste. The results show that urea could deepen the color of the ink-jet-printed fabric to achieve the highest color yield when 10 g of urea was used in the pretreatment print paste. Black showed the highest color yield, followed by cyan, magenta, and finally yellow. The order of effect was similar to that of the results reported previously.⁸

However, an interesting observation, based on Figure 4, is that when the amount of urea used in the pretreatment print paste was more than 10 g, the color yield of the ink-jet-printed fabrics decreased. When the amount of urea was further increased to 20 g, the color yield of the ink-jet-printed fabric dropped significantly, and it was paler than that when 5 g of urea was used. Such a drop in the color yield with respect to an increasing amount of urea used in the pretreatment print paste might be due to an increase in the moisture regained by the fibers during the steaming process. Because of the hygroscopic nature, urea served as a moisture-absorbing agent in the steaming process. A large amount of urea used in the pretreatment print paste could enhance the moisture absorption, which could cause the hydrolysis of reactive dyes during the steaming process.

Effect of the steaming time on the pretreatment print paste

Figure 5 demonstrates the effect of the steaming time on the color yields of different ink-jet-printed

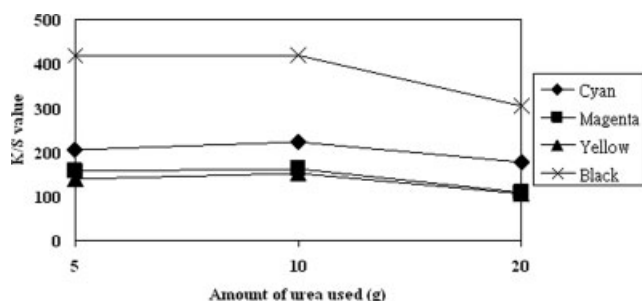


Figure 4 Effect of the amount of urea on the color yield of four different colors.

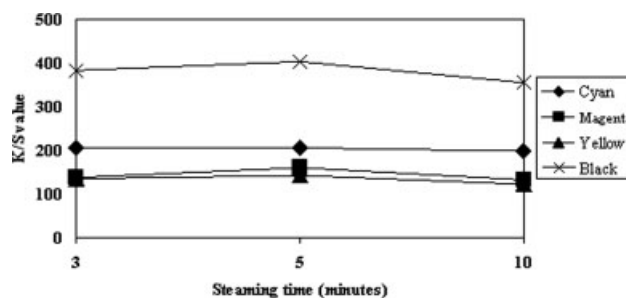


Figure 5 Effect of the steaming time on the color yield of four different colors.

fabrics. Black showed the highest color yield, followed by cyan, magenta, and yellow. The optimum K/S values of all four different colors were obtained at a steaming time of 5 min.

In the printing process, steam serves as a convenient source of both water and heat, which can be transferred rapidly and uniformly over the surface area of ink-jet-printed fabrics. However, when the steaming time is prolonged to more than 5 min, the color yield of the ink-jet-printed fabrics will be reduced to different extents. With respect to prolonged steaming time at a higher temperature (110°C in this article), the decomposition of urea will occur, producing ammonia products inside the steaming chamber. Because of the reaction of the reactive dye with ammonia and the loss of the alkali, a lower color yield will be obtained under these conditions. Furthermore, a prolonged steaming time will also provide sufficient moisture for the urea to absorb. As a result of the combination effect, hydrolysis might occur and reduce the color yield.

Optimum conditions and effects of chitosan for different application methods on the color yield of ink-jet-printed fabric

Orthogonal analysis is a useful and simple technique for analyzing the process variables or factors involved in a production process. Previous research^{13–16} has shown that orthogonal analysis can provide a simple and convenient way of finding the optimum conditions and the level of importance of different factors in a production process.

After considering the results obtained from the orthogonal analysis, as shown in Table III, we concluded that all four factors being studied—chitosan, urea, sodium bicarbonate, and the steaming time—could affect the K/S value by having different effects on the final color yield. However, the level of importance based on the orthogonal analysis^{8,13,15} was in the order of urea > chitosan > sodium bicarbonate > steaming time. On the basis of the results of the orthogonal analysis, the optimum conditions for the one-bath chitosan treatment with chitosan as a

TABLE IV
Color Yields of the Different Ink-Jet-Printed Fabrics

Sample	Cyan	Magenta	Yellow	Black
Control fabric	110.75	95.66	90.30	260.88
One-bath chitosan treatment fabric ^a	88.60	76.53	72.24	208.70
Two-bath chitosan treatment fabric	120.83	104.23	100.33	284.97

^a The treatment was performed under the optimum conditions.

thickener for the pretreatment printing paste were concluded to be 40 mL of chitosan, 10 g of urea, 8 g of sodium bicarbonate, and 5 min of steaming. To verify the printed quality by means of the color yield under the optimum conditions, further experiments were conducted with the use of a control fabric, and the results are shown in Table IV.

For the one-bath chitosan treatment, the results shown in Table IV demonstrate clearly that the cotton fabric treated with chitosan under the optimum conditions could achieve a better color yield in comparison with those shown in Table III. However, about 80% of the final color yield was obtained for all four colors of the one-bath chitosan treatment fabric in comparison with the control fabric. The lowered color yield may have been due to the neutralization effect that occurred during the mixing of the chitosan solution and sodium bicarbonate in the preparation of the pretreatment print paste. The neutralization effect might thus reduce the effectiveness of the pretreatment print paste during the ink-jet printing process. To study the effect of the neutralization effect, a two-bath chitosan treatment was proposed for applying chitosan to cotton fabrics as a thickener in the ink-jet printing process, and the results are shown in Table IV.

Table IV shows the color yields of the four different colors of the ink-jet-printed fabrics with different types of treatments. The two-bath chitosan treatment fabrics had the best color yield in comparison with the one-bath chitosan treatment and control fabrics. For the one-bath chitosan treatment fabrics, although the chitosan was confirmed to be able to replace

sodium alginate as a thickener for ink-jet printing, the color yield was only 80% in comparison with that of the control fabric. This reduction in the color yield was probably due to the neutralization effect between the chitosan and sodium bicarbonate in the pretreatment print paste. When the chitosan was applied to the cotton fabric, it was believed that the amino group present in chitosan could take up a proton from the slightly acidic bath, and so $-\text{NH}_3^+$ groups were formed. These groups, being electropositive in nature, could facilitate the transfer of the negatively charged dye anion from the bath onto the fabric, thereby improving exhaustion.¹²

Color fastness of the ink-jet-printed fabrics

The colorfastness grading of the ink-jet-printed fabrics is summarized in Table V; both the two-bath chitosan treatment and one-bath chitosan treatment cotton fabrics had better color fastness properties than the control fabric, with an improvement of at least half a grade.

The improvement in the color fastness of the two-bath chitosan treatment and one-bath chitosan treatment fabrics might be associated with the introduction of primary amino groups into the cellulosic fiber structure. After these groups were deposited into crevices between the fibers, they most likely imparted a cationic surface that attracted the oppositely charged reactive dye anions.¹⁷ As a result, the ink-jet printability of the two-bath chitosan treatment and one-bath chitosan treatment fabrics was improved.

TABLE V
Color Fastness Results for the Different Ink-Jet-Printed Fabrics

Sample	Washing (cyan/magenta/ yellow/black)		Crocking (cyan/magenta/ yellow/black)	
	Staining ^a	Color change ^b	Wet	Dry
Control fabric	4/4/4/4	4	3/3/3/3	4/4/4/4
One-bath chitosan treatment fabric ^c	4-5/4-5/4-5/4-5	4-5	4/4/4/4	4-5/4-5/4-5/4-5
Two-bath chitosan treatment fabric	4-5/4-5/4-5/4-5	4-5	4/4/4/4	4-5/4-5/4-5/4-5

^a Each of the four colors yielded the same result on the multifiber fabric, and so only one value is given.

^b On the tested fabric.

^c The treatment was performed under the optimum conditions.

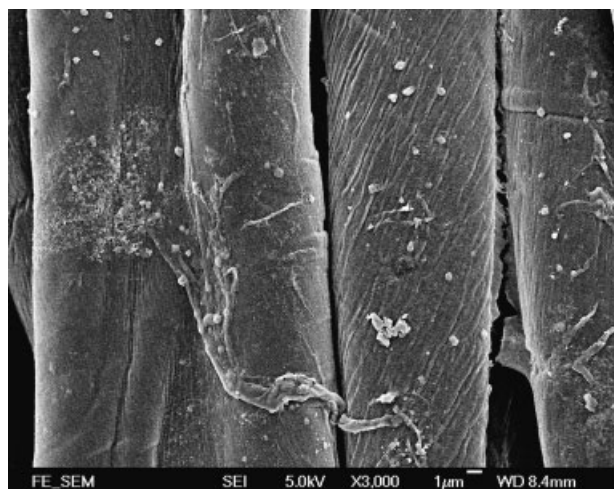


Figure 6 Surface appearance of the control cotton fabric in the pretreatment stage.

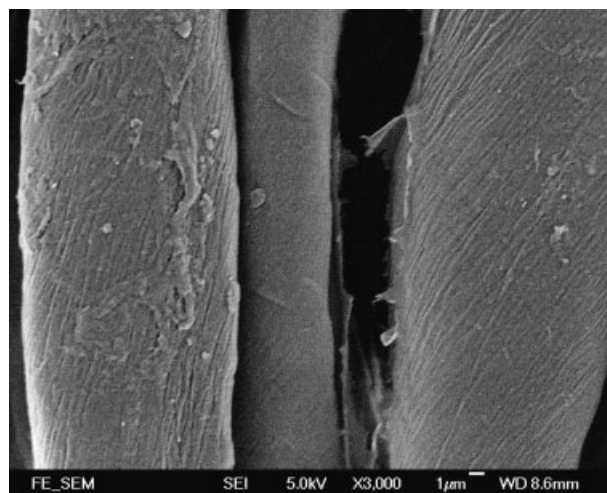


Figure 8 Surface appearance of the chitosan-containing cotton fabric in the pretreatment stage.

Surface appearance of the ink-jet-printed cotton fabric

The surface appearance of the control and chitosan-containing cotton fabrics (i.e., two-bath chitosan treatment and one-bath chitosan treatment fabrics) was morphologically observed with scanning electron microscopy, as shown in Figures 6–9.

Figures 6 and 7 show the surface appearance of the control fabric in the pretreatment stage and after-washing stage, respectively. Sodium alginate adhered initially to the cotton fiber surface in the pretreatment stage. However, it was completely removed from the fiber surface in the after-washing stage.

On the other hand, Figures 8 and 9 show that chitosan also adhered initially to the surface of the

cotton fiber surface in the pretreatment stage. On the contrary, chitosan remained on the fiber surface in the after-washing stage. Furthermore, the chitosan that was deposited on the crevices formed crosslinks between the cotton fibers.

When comparing the scanning electron microscopy images of the control and chitosan-containing cotton fibers, we found that the surface of the chitosan-containing fibers had many long, narrow lines. The scanning electron microscopy analysis made it clear that the treatment of the cotton fibers with chitosan resulted in a unique morphological form having a more textured surface than the control fabric. This was suggested to be caused by polymer precipitation.¹⁷

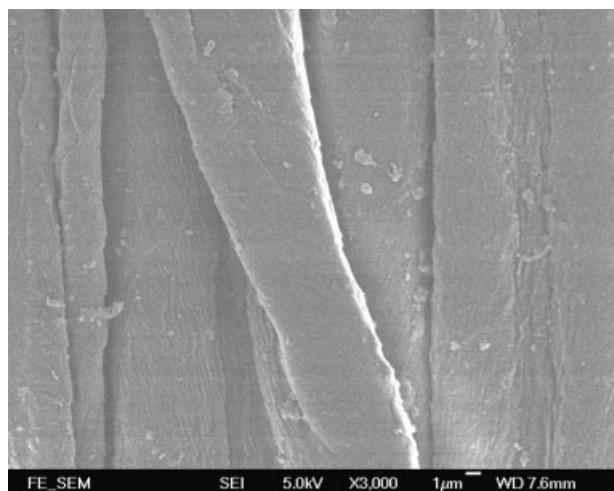


Figure 7 Surface appearance of the control cotton fabric after washing.

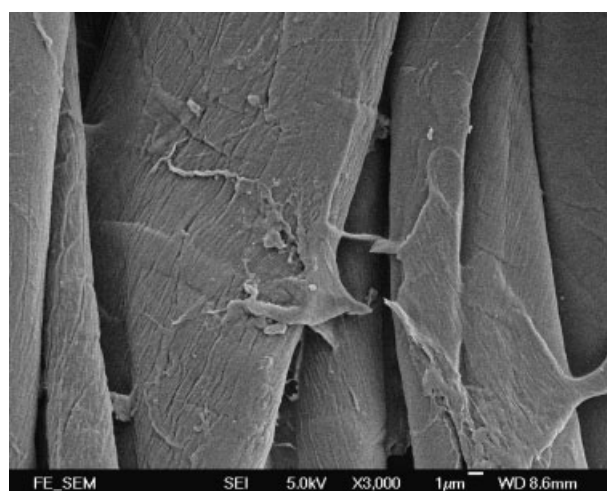


Figure 9 Surface appearance of the chitosan-containing cotton fabric after washing.

TABLE VI
Outline Sharpness of the Ink-Jet-Printed Fabrics

Sample	Color							
	Cyan		Magenta		Yellow		Black	
	Warp (mm)	Weft (mm)	Warp (mm)	Weft (mm)	Warp (mm)	Weft (mm)	Warp (mm)	Weft (mm)
Control fabric	82	81	82	81	82	81	82	81
One-bath chitosan treatment fabric ^a	81	80	81	80	81	80	81	80
Two-bath chitosan treatment fabric	81	80	81	80	81	80	81	80

^a The treatment was performed under the optimum conditions.

Outline sharpness of the ink-jet-printed fabric

The outline sharpness of the ink-jet-printed pattern was measured by the optical analysis method, and the results are shown in Table VI.

For both control and chitosan-containing fabrics, the ink-jet-printed patterns of the four different colors in the warp direction were thicker than those in the weft direction. This might have been due to the differential wicking effect caused by the warp and weft yarns. When considering the width of the printed pattern, we found that the patterns printed on the chitosan-containing fabrics were narrower than those of the control fabric in both the warp and weft directions. The results confirmed that the chitosan treatment could enhance the outline sharpness of the prints as a result of strong ionic attractions between the cationic cotton and anionic reactive inks. The two-bath-treated and chitosan-treated cotton fabrics had the same outline sharpness.

Determination of the tensile strength of the printed fabric

The tensile strength of the differently treated cotton fabrics, as reflected by the breaking load, is shown in Table VII. Drops in the breaking load of about 2 and 0.8% (in both the warp and weft directions) were noted for the two-bath chitosan treatment and one-bath chitosan treatment fabrics, respectively, in comparison with the control fabric. The slight decrease in the breaking load might have been due

TABLE VII
Breaking Load of the Ink-Jet-Printed Fabrics

Sample	Breaking load (N)	
	Warp direction	Weft direction
Control fabric	410.60	247.00
One-bath chitosan treatment fabric ^a	407.55 (↓0.7%)	245.02 (↓0.8%)
Two-bath chitosan treatment fabric	401.44 (↓2.2%)	241.54 (↓2.2%)

^a The treatment was performed under the optimum conditions.

to the acid damage that occurred inside the one-bath chitosan treatment cotton fabric fabricated at pH 5 in an acidic medium. In the one-bath chitosan treatment fabric, the neutralization effect minimized the acid damage, but it did not contribute much in the two-bath chitosan treatment. Because the cotton fabrics were first treated with acetic acid and were exposed to a high curing temperature, both factors may have contributed to the further reduction of the fabric tensile strength and hence reduced the breaking load.

Antibacterial evaluation of the ink-jet-printed fabrics

AATCC test method 100 was used to determine the antibacterial activity of the ink-jet-printed fabrics. Table VIII shows the bacterial concentration of *Staphylococcus aureus* bacteria with respect to the ink-jet-printed fabrics at 0 and 48 h.

The results indicated that the chitosan-containing fabrics, that is, the two-bath chitosan treatment and one-bath chitosan treatment fabrics, showed positive results of the antibacterial effect; this meant that the bacteria could be completely killed by the chitosan present in the treated cotton fabric. Therefore, the chitosan treatment for cotton fabric was very effective for resisting bacteria in comparison with the control fabric. Although the control fabric containing sodium alginate had antibacterial function, its

TABLE VIII
Antibacterial Evaluation

Sample	Bacterial concentration		
	0 h	48 h	Bacterial removal (%)
Control fabric	2.4×10^8	7.1×10^7	70.54
One-bath chitosan treatment fabric ^a	8.1×10^7	0	100
Two-bath chitosan treatment fabric	5.7×10^8	0	100

^a The treatment was performed under the optimum conditions.

performance was worse than that of the chitosan-containing fabric.

CONCLUSIONS

The use of chitosan as a thickener in the pretreatment print paste for ink-jet printing was explored. On the basis of the results of different color fastness tests, chitosan in principle could work as a pretreatment print paste thickener. However, the final color yield obtained from chitosan-containing cotton fabrics depended greatly on the stage of the chitosan application. Nevertheless, the color fastness properties and the outline sharpness of the prints of cotton fabrics were greatly improved by the chitosan treatment.

With the help of an orthogonal analysis, the importance of different process factors was found to be in the order of (1) the amount of urea used, (2) the amount of chitosan used, (3) the amount of sodium bicarbonate used, and (4) the steaming time. On the basis of the results of the orthogonal analysis, the optimum conditions with chitosan as a thickener for the pretreatment print paste were concluded to be 40 mL of chitosan, 10 g of urea, 8 g of sodium bicarbonate, and 5 min of steaming.

In addition, a two-bath chitosan treatment has been tentatively developed to separate chitosan from sodium bicarbonate and urea before it is padded onto the fabric surface to minimize the neutralization effect. On the basis of the results of the highest color

yield obtained on the cotton fabric, it has been confirmed that a two-bath method has been successfully developed. In addition, chitosan can impart a higher antibacterial property with a slight reduction in the tensile strength of the cotton fabric.

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