Chemical Silver Plating on Polyester/Cotton Blended Fabric

S. Q. Jiang, E. Newton, C. W. M. Yuen, C. W. Kan

Institute of Textiles and Clothing, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, People's Republic of China

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ABSTRACT: Chemical plating is a metallizing process that can impart unique properties to textile fabrics. It has great potential for use in textile production, especially in the functional and decorative aspects. The present study examined the feasibility of applying chemical silver plating to a polyester/cotton blended fabric (T/C fabric) as well as investigating the properties of the silver-plated T/C fabric. It was found that chemical silver plating helped to produce T/C fabric with a novel appearance and to improve its performance. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 100: 4383–4387, 2006

Key words: fibers; modification; surfaces

INTRODUCTION

Reflective metallic surfaces can provide individuals with a way to look at themselves, and they play an important role in the consumer market and in technical applications. Metallized fabrics is an attractive textile finishing process that adds value and improves functions.[1] With the advent of synthetic fibers and the development of metallizing technology, there has been extensive research in how to produce functional fabrics.[2] Some studies used chemical plating successfully produce conductive fabric.[3–5] New developments in metallizing fabrics have been achieved with the use of chemical plating because of its superior performance.[6] Chemical silver plating has been applied to textile decorating in order to modify fabric performance. Metallized fabric in particular has an identity and a quality of brightness that can create beautifully reflected and lustrous images.[7,8] In our previous research, the chemical silver-plating method was successfully applied to cotton and polyester fabrics separately.[9] Hence, it was expected that such a method could also be applied to a polyester/cotton blended (T/C) fabric. Although T/C fabric is popularly used in textile and clothing industries, the underlying properties of metallized T/C fabric are still not fully understood. The present study attempted to determine the effect of chemical silver-plating treatment on T/C fabric. It was hoped that the process developed in this study for metallizing T/C fabric would enhance the qualities and aesthetics of T/C fabric. In addition, the final properties of the silver-plated T/C fabric also were evaluated.

Correspondence to: S. Q. Jiang (tckinor@inet.polyu.edu.hk).
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EXPERIMENTAL

Materials

The T/C fabric used in this study was bleached plain woven T/C fabric (35% polyester/65% cotton) with a thickness of 0.31 mm and an average mass per unit area of 108 g/m^2. The sample was washed by being soaking in a solution of laboratory detergent for 20 min and then rinsed in deionized water, according to ASTM D1776-04. A typical chemical-plating solution was used. The solution was composed of silver nitrate, a reducing agent, and complex agents including alkali, buffer, and stabilizer to control and promote the autocatalytic process. The activators used, stannous chloride, hydrochloric acid, silver nitrate, sodium hydroxide, ammonia, and glucose, were of analytical grade.

Chemical silver plating

For deposition of silver to occur on a particular surface of the T/C fabric, it was necessary for the fabric surface to act as a catalyst. The activation energy of the catalytic route was lower than the homogeneous reaction in solution.[10,11] In accordance with the method of chemical silver plating for a nonmetal substrate,[12] three main steps—pretreatment, plating process, and posttreatment—were employed in the experiment. Details of the parameters of the continuous chemical treatment were reported previously.[9] After chemical silver plating, the samples were rinsed in deionized water directly, heat cured for 1 min, and then conditioned according to ASTM D1776-04 before measurement.

Fabric weight

The weight of fabric specimens 100 mm^2 in size before and after treatment was measured with a Shimadzu BX300 meter. On the basis of the reaction time, the average rate of deposition, measured as the change in weight (g) per minute, was calculated by eq. (1):

$$S_w = (W_f - W_o)/t \quad (1)$$

where S_w is the average rate of deposition according to increase in weight (g/min), W_f is the final weight (after treatment; g), W_o is the original weight (before treatment; g), and t is the reaction time (min).

Fabric thickness

Fabric thickness before and after treatment was measured by a fabric thickness tester (Hans Baer AG CH, Zurich, Switzerland) under a pressure of 5 g/cm^2. The average rate of deposition as measured as the increase in thickness (mm) per minute, was calculated by eq. (2):

$$S_t = (T_f - T_o)/t \quad (2)$$

where S_t is the average rate of deposition according to increase in thickness (mm/min), T_f is the final thickness (after treatment; mm), T_o is the original thickness (before treatment; mm), and t is the reaction time (min).

Fabric bending rigidity test

A FAST-2 Bending Meter (Ryde, Australia) was employed to measure the degree of bending rigidity of the fabric in both the warp and weft directions. Original and silver-plated fabric samples in both directions were tested for stiffness as directed in ASTM D1388-96. The flexural rigidity of the fabrics was calculated as fabric bending length multiplied by fabric mass per unit area using eq. (3):

$$G = W \times C^3 \quad (3)$$

where G (N cm) is the average flexural rigidity, W (N/cm^2) is the fabric mass per unit area, and C (cm) is the fabric bending length.

Assessment of color change

Four standard testing methods—ISO 105-C06 : 1994, ISO 105-E04 : 1994, ISO 105-X12 : 2001, and ISO 105-B02 : 2000 (Xenon arc fading-lamp test) for testing colorfastness to domestic and commercial laundering, perspiration, rubbing, and artificial light, respectively—were used to assess change in color of the silver-plated fabric under different conditions.

Measurement of fabric color

The appearance of both the original and the treated fabrics was measured with the Commission International I Eclarirage (CIE) scale, $L^* a^* b^*$ (L^*, lightness; a^*, redness/greenness; and b^*, yellowness/blueness), using a Macbeth Color-Eye 7000A at D65/10°.

Measurement of ultraviolet radiation

In the measurement of ultraviolet radiation penetration, all the silver-plated fabric samples were evaluated with a UV–visible spectrophotometer (Varian, Cary 300 Conc) with a wavelength ranging from 280 to 400 nm.

Antistatic properties

The antistatic properties of T/C fabric were determined using resistance measurement with a static voltmeter R-1020 (Rotchschild, Swiss). Two fabric specimens each 10 × 100 mm in size were cut and tested in both the warp and weft directions. Each specimen was fixed between two fixation screws. The insulated terminal was charged from the built-in DC source. The elapsing time, t (s), was defined as the time required to discharge half the charge in the specimen. The resistance [R (Ω)] of the specimen was calculated using eq. (4):

$$R = 1 \times 10^{11} \times t \quad (4)$$

Measurement of antibacterial properties

The antibacterial properties of T/C fabric were investigated according to AATCC test method 147-2004 by incubating a bacterial solution of both *Escherichia coli* and *Staphylococcus aurous* at a density of 10^8 CFU/mL at 37°C for 24 h. The incubated plates were examined so that the interruption of growth along the streaks of inoculum beneath the specimen together with a clear zone of inhibition beyond its edge could be determined. The average width of a zone of inhibition along a streak on either side of the test specimen was calculated using eq. (5):

$$W = (T - D)/2 \quad (5)$$

TABLE I
Changes in Weight, Thickness, and Bending Rigidity of T/C Fabric After Chemical Plating

Specimen		Weight (g/m^2)	Thickness (mm)	Bending (N cm) warp	Bending (N cm) weft
T/C	Original	108	0.30	3.6	2.5
	Silver-plated	126	0.34	3.9	3.0
	Increase (%)	16.7	13.3	8.3	20.0

where *W* (mm) is the width of the clear zone of inhibition, *T* (mm) is the total diameter of the test specimen, and *D* (mm) is the diameter of the test specimen.

Surface observation

The surface of the silver-plated T/C fabric structure was studied using a JSM-6335F field emission scanning electron microscope (SEM) at a magnification of 30,000×.

RESULTS AND DISCUSSION

Effect of chemical silver plating on weight, thickness, and bending rigidity of T/C fabric

Changes in the physical properties weight, thickness, and bending after chemical-plating treatment of the T/C fabric are shown in Table I. The results showed that the chemically silver-plated T/C fabric was heavier than the untreated fabric, with a weight increase of 16.7%. The higher weight of the silver-plated fabric confirmed that silver ions had clung effectively to the surface of the T/C fabric. The fabric exhibited a 13.3% increase in thickness after being subjecting to chemical-plating treatment. The fabric flexural, that is, its bending behavior, was important for evaluating the fabric handle. The bending rigidity of the silver-plated T/C fabric increased by 8.3% in the warp direction and by 20% in the weft direction. The bending rigidity results indicated that the handle of the silver-plated T/C fabric was stiffer than that of the original fabric.

The rate of deposition of silver particles was evaluated according to the changes in both the weight and the thickness of the T/C fabric. For a total deposition time of 20 min, the results revealed that the deposition rate of T/C fabric expressed as an increase in weight was 9×10^{-3} g/min and expressed as an increase in thickness was 2×10^{-3} mm/min. These results showed that the T/C fabric had better water absorption, thereby leading to increased speed of the reaction during the entire process with both the acid sensitization and alkaline plating treatments.

Assessment of color change

The washing treatments resulted in a change in the color of the silver-plated T/C fabric to grade 4–5. This confirmed that the silver particles performed well during washing. It was observed that there was good color change, grades 4–5, in the perspiration fastness test in both the acid and the alkali solutions, and the silver-plated T/C fabric was not affected. The crocking fastness of the silver particles in the T/C fabric also was investigated. In dry rubbing conditions, the degree of staining was recorded as grade 4, which predicted that the silver-plated T/C fabric had better dry crocking fastness. On the other hand, the wet crocking fastness had a poor result, grade 2, showing that the rubbing fastness of the silver-plated T/C fabric was relatively poor compared with the commercial requirement.

The silver-plated T/C fabric sample was measured by a Xenotest Alpha LM (Heraeus Industriete Chnik) in order to test the colorfastness of silver foil with respect to light radiation. The results showed the silver-plated T/C fabric to be grade 4–5, which was considered as good and met the commercial requirement of light fastness. This showed that the silver-plated T/C fabric was capable of resisting artificial light in the prescribed conditions of a simulated light climate. Hence, the silver-plated T/C fabric was quite stable in normal lighting conditions.

Measurement of color

The appearance of T/C fabric changed from white to gray in color after the silver-plating treatment. Table II shows the color appearance of the silver-plated T/C sample. In addition, the silver-plated T/C fabric showed reduced brightness of −16.82 when compared with the original fabric. Because the alkali plating solution attacked the white fabric, causing it to become brown, and the color obtained had positive a^* and b^* values for T/C. Thus, the silver-plated T/C fabric had higher values of a^* and b^* than did the original fabric and was evaluated as being brownish in color. The sample became grayer after the silver-plating process, as reflected by the lower L^* values compared to those of the untreated fabric. In view of the overall color appearance results, the T/C fabric had a silver gray effect.

TABLE II
Measurement of Color Appearance of Silver-Plated Fabric

T/C	CIE L* a* b* (D65/10°) L*	a*	b*	C*	h
Original	92.84	−0.45	3.02	3.06	98.51
Silver-plated	46.44	1.35	9.23	9.32	81.69
Change	−46.40	+1.80	+6.20	+6.27	−16.82

TABLE III
Ultraviolet Radiation Penetration Factor of Original and Silver-Plated Fabrics

T/C	Calculated UPF	UPF Rating
Original	16.73	15
Silver-plated	97.03	50+

Ultraviolet radiation penetration

Table III summarizes the UPF results of the ability to shield the penetration of ultraviolet radiation. The results showed that the original T/C fabric was not good for protecting from ultraviolet radiation, as indicated by the ultraviolet radiation penetration factor (UPF) rating of 15. However, the chemical plating results confirmed that the silver-plated T/C fabric provided excellent protection from ultraviolet radiation, as indicated by the UPF rating of 50+. This suggested that the silver-plated T/C fabric improved the quality of protection from ultraviolet radiation with good results.

Determination of static half-life and measurement of electrical resistance

It can be seen in Table IV that the average static half-life value of the silver-plated T/C fabric was almost null in both the warp and the weft directions. Hence, the fabric was considered to possess good antistatic property as a result of the silver-plating treatment. When compared with that of the original fabric, the antistatic property of the silver-plated fabric decreased with time of >1.0 s in the warp direction and >0.9 s in the weft direction. The smaller the static half-life value, the more enhanced would be the prevention of static charge of the T/C fabric.

Antibacterial properties

The silver-plated T/C fabric was covered with a nutrient medium containing a culture of the test bacteria, *E. coli* and *S. aureus*. They were spread to produce uniform growth under the culture conditions at 37°C for 24 h. The silver-plated T/C fabric shown in Figures 1 and 2 was very effective against the two test bacteria,

TABLE IV
Antistatic Properties of Untreated and Silver-Plated T/C Fabrics

T/C	Average static half-life (s)	
	Warp	Weft
Original	1.5	1.4
Silver-plated	<0.5	<0.5
Decrease	>1.0	>0.9

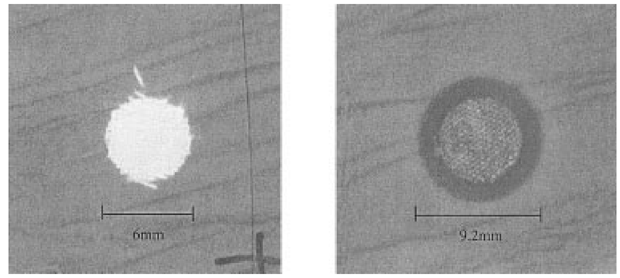

Figure 1 Inhibition zone with a *E. coli* bacterium on the original T/C fabric (left) and on the silver-plated T/C fabric (right).

as shown by the appearance of clear halos around the plated specimens. The assessed resistance diameter scales are listed in Table V. The experimental results showed that the T/C fabric exhibited similar antibacterial properties, and thus, the silver-plating treatment imparted good antibacterial properties to the fabric.

Measurement of surface structure with SEM

To have a more detailed insight into the change in the surface property of the fiber, the T/C fabric was examined by a scanning electron microscope (SEM). The SEM results indicated that the silver-plated fibers were uniformly covered by silver particles, as shown in Figures 3 and 4, at a magnification of 30,000×. The grain size of the metal particle aggregation ranged from 30 to 100 nm in diameter. Detailed SEM pictures showed that the plated layer was composed of a mass particle cluster zone evenly distributed on the surface of the fibers. Both the cotton and polyester fibers of T/C fabric were covered with the dense silver particles, which were clearly visible. These results indicated that the effect of chemical silver plating was sufficient and effective to change the microstructure of the T/C fabric.

Overall analysis

The chemical plating method could be employed to deposit silver particles on the fabric surface for met-

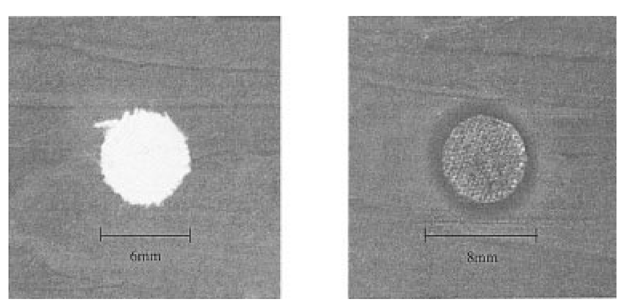

Figure 2 Inhibition zone with a *S. aureus* bacterium on the original T/C fabric (left) and on the silver-plated T/C fabric (right).

TABLE V
Assessed Diameters of Antibacterial Areas

T/C	Diameter of anti-bacterial area (mm)	
	Escherichia coli	*Staphylococcus aureus*
Original	6.0	6.0
Silver-plated	9.2	8.0

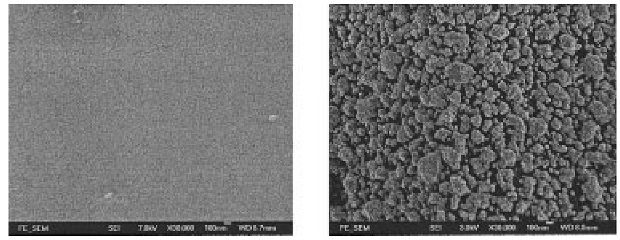

Figure 4 Appearance of the surface of untreated polyester fiber (left) and silver-plated polyester fiber (right) in the T/C fabric (SEM with 30,000× magnification).

allization of nonconductive T/C fabric. To enhance the successful deposition of plating, only the autocatalytic reaction could be used. The performance of metallized T/C fabric was correlated with the concentration of the solution. Furthermore, the combination of metal and reducing agent required a specific pH range and bath formulation. The experimental results indicated that the surface characteristics were sensitive enough to load the silver particles onto the cotton and polyester fibers. According to the SEM investigation, the chemical silver plating could render a uniform distribution with dense silver granules on both sides of the T/C fabric. The silver-plated T/C fabric was stiffer than the untreated fabric. By assessing the color change, the metallized T/C fabric showed good colorfastness to washing, perspiration, and light. This investigation also proved that the chemical silver-plating method could impart antibacterial function to T/C fabric. In addition, the silver-plated T/C fabric performed well in protection from the penetration of ultraviolet radiation and in antistatic properties. Such special abilities were mainly a result of the silver particles have a higher shielding property and good conductivity. From the experimental results, it was obvious that chemical silver plating could produce a functional T/C fabric.

CONCLUSIONS

Chemical silver-plated T/C fabric was developed with the functional properties for commercial application. The chemical plating appeared to be a good approach for metallic modification of the surface of nonconducting T/C fabric. The study specifically investigated the modification of chemical silver-plated T/C fabric, which showed the following advantages: (1) nonconducting T/C fabric could be metallized; (2) silver particles were deposited and uniformly distributed on both sides of the T/C fabric; (3) many application functions were improved such as antibacterial properties, antistatic properties, and ultraviolet radiation shielding; and (4) a silver color appearance was attained. The chemical silver-plating process can meet textile specification requirements and can immediately provide a T/C fabric that is unique in appearance.

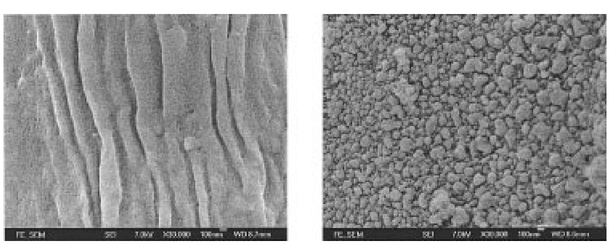

Figure 3 Appearance of the surface of untreated cotton fiber (left) and silver-plated cotton fiber (right) in the T/C fabric (SEM with 30,000× magnification).

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