Chemical Silver Plating and Its Application to Textile Fabric Design

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, China

Received 26 April 2004; accepted 8 September 2004
DOI 10.1002/app.21541
Published online in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: Metalization is one of the finishing processes in textile treatments that can produce fabrics with a unique appearance. It has great potential for textiles and garments, including functional and decorative effects. Chemical plating is an autocatalytic deposition method for precision work in conventional manufacturing. In this study, the operation and final properties of the chemical silver plating of cotton and polyester fabrics were investigated. The results showed that a specific performance of silver-plated fabric could be obtained if the optimum chemical-plating conditions were chosen. In addition, a fabric design practice employed by this chemical technique with a craft approach achieved a diverse effect. © 2005 Wiley Periodicals, Inc. J Appl Polym Sci 96: 919–926, 2005

Key words: fibers; modification; surfaces; thin films

INTRODUCTION

The coating of fabrics is a textile finishing process that adds value and improves functions.[1] With the advent of synthetic fibers, less expensive ways have been found to make metallic fabrics in the twentieth century. Metalized fabric in particular has an identity and a quality of brightness that can create beautifully reflected and lustrous images. Reflective surfaces can offer an individual look for technical processes and are very popular in the contemporary consumer market and technical applications.

Metalized fabric can be produced by a lamination process between a metal powder or foil and a fabric with a binder.[2] Vacuum deposition and sputtering coating have been applied to polyester fabrics with aluminum, titanium, and stainless steel.[3] Furthermore, a silver-plated product usually is produced by electroplating onto the surface of a conductive material.[4] Some researchers have discussed a process for achieving the results of conductive fabrics with chemical silver plating.[5] Chemical plating is a method originally used for precision work in manufacturing. Although chemical silver plating has been employed for more than 50 years,[6] it is still generally used in the manufacture of reflected mirror surfaces and the pretreatment of electroplating on nonconductive materials such as acrylonitrile–butadiene–styrene, ceramics, and glass. Unlike the electroplating process, in which externally supplied electrons act as reducing agents in autocatalytic deposition, chemical silver coatings are formed as a result of a chemical reaction between the reducing agent and metal ions present in the solution.

Over the past years, very limited fabric design involving the creation of colors and patterns has been studied with chemical silver plating. Therefore, this study was aimed at determining the effects of chemical treatments on two fabrics, cotton and polyester. We hope that this newly developed metalizing process for fabrics can enhance the tactile qualities and aesthetic considerations of fabrics; this was evaluated thoroughly in this study. This study also involved the study of originality in the area of metallic fabric design. For the characterization of the properties, the final performances of two silver-plated fabrics were evaluated individually. Moreover, for design applications, this study could improve the development of both aesthetic and functional effects through metalization.

EXPERIMENTAL

Materials

Two fabric samples, cotton and polyester, were chosen for this study. The characteristics of the two types of white fabric specimens with a plain-weave construction are summarized in Table I.

A typical chemical-plating solution was used for the experiments; it consisted of silver nitrate, a reducing agent, and complex agents such as an alkali, a buffer, and a stabilizer to control and promote the autocatalytic process. The activators were stannous chloride,

Correspondence to: S. Q. Jiang (kinor.j@polyu.edu.hk).
Contract grant sponsor: Hong Kong Polytechnic University.

Journal of Applied Polymer Science, Vol. 96, 919–926 (2005)

TABLE I
Fabric Specifications

Fabric (100 mm × 100 mm)[a]	Ends (cm)	Pick (cm)	Weight (g/m^2)	Thickness (mm)[b]
100% cotton	28	23	144	0.42
100% polyester	38	36	72	0.28

[a] All fabrics were conditioned according to ASTM D 1776-04 before testing.
[b] At a pressure of 5 g/cm^2.

hydrochloric acid, silver nitrate, sodium hydroxide, an ammonium solution, and glucose; they were analytical-reagent-grade.

Chemical silver plating

For localized silver deposition on a particular surface of the fabrics, the fabric surface had to act as a catalyst. The activation energy of the catalytic route was lower than the homogeneous reaction in solution. A smooth deposition was obtained when the autocatalytically deposited metal acted as a catalyst.[7,8] For chemical silver plating on the nonmetal substrates,[9] the main steps were precleaning, sensitization, plating, and posttreatment.

For the silver particles to be well distributed on the fabric surface uniformly, all the fabric samples were pretreated by rinsing with solution A for 20 min. After the rinsing, the fabrics were further cleaned with deionized water. The cleaned fabrics then underwent surface sensitization with solution B as a catalyst for 10 min. After further soft rinsing in deionized water, the sensitized fabric samples were finally immersed in the chemical-plating solution, which contained both solution C and solution D. In the plating experiment, the mixture ratio of solution C to solution D was 1/3 (v/v). Continuous stirring was applied during the sensitization and plating processes so the reaction between the fabrics and reagents was uniform. After chemical silver plating, the samples were rinsed in running water directly. Finally, the fabrics were conditioned according to ASTM D 1776-04 before the measurements. The experimental procedures are summarized in Table II.

Fabric weight

The weights of the fabric specimens (100 mm × 100 mm) before and after the treatment were measured with a Shimadzu BX300 weight meter (Hong Kong, China).

Fabric thickness

The thickness of each fabric before and after the treatment was measured with a Hans Baer AG CH-Zurich Telex 57767 fabric thickness tester (Switzerland) at a pressure of 5 g/cm^2.

Fabric bending test

A FAST-2 bending meter was used to measure the degree of bending of the fabric in both the warp and weft directions.

Color change assessment

Four standard testing methods were used to assess the color changes in the plated fabrics under different application conditions: (1) ISO 105-C06:1994 (color fastness to domestic and commercial laundering), (2) ISO 105-E04:1994 (color fastness to perspiration), (3) ISO 105-X12:2001 (color fastness to rubbing), and (4) ISO 105-B02:2000 (color fastness to artificial light: xenon arc fading lamp test).

Color measurements

The fabric appearances (both original and untreated) were measured with the Commission International I Eclairage (CIE) scale *L**, *a**, and *b** (L* = lightness, a* = redness/greeness, and b* = yellowness/blueness) with a Macbeth Color-Eye 7000A (New York) at D65/10°.

TABLE II
Experimental Procedures

Item	Concentration of each solution	Application condition
Precleaning	Solution A: 2% nonionic detergent	1000 mL, 20 min, 40 ± 1°C
Sensitization	Solution B: 5 g of stannous chloride ($SnCl_2 \cdot 2H_2O$) and 5 mL of hydrochloric acid (HCl; 37%) in 1000 mL of double-deionized water	1000 mL, 10 min, 25 ± 1°C
Plating	Solution C: 12 g of silver nitrate ($AgNO_3$), 8 g of sodium hydroxide (NaOH), a few drops of an ammonium solution (NH_4OH; 28%) in 1000 mL of double-deionized water	500 mL solution C and 1500 mL solution D, 50 min, 10 ± 1°C
	Solution D: 2.6 g of glucose ($C_6H_{12}O_6$) in 1000 mL of double-deionized water	
Posttreatment	Cleaning with deionized water	20 min, 40 ± 1°C
	Heat-set	1 min, 150 ± 1°C

TABLE III
Changes in the Weight, Thickness, and Bending of Fabrics After Chemical Plating

Specimen (100 mm × 100 mm)		Weight (g)	Thickness (mm)	Bending (μN m)	
				Warp	Weft
Cotton	Original	1.44	0.42	14.4	7.9
	Silver-plated	1.60 (↑ 11.1%)	0.44 (↑ 4.8%)	14.5 (↑ 0.7%)	9.4 (↑ 18.9%)
Polyester	Original	0.72	0.26	1.3	1.5
	Silver-plated	0.84 (↑ 16.7%)	0.27 (↑ 3.9%)	0.9 (↓ 30.8%)	1.0 (↓ 33.3%)

Ultraviolet (UV) radiation measurements

For the measurement of UV radiation penetration, all the plated fabric samples were evaluated with a Varian Cary 300 ultraviolet–visible spectrophotometer (Mulgrave, Victoria 3170, Australia) at a wavelength range of 280–400 nm.

Antistatic properties

The antistatic properties of the fabrics were determined from resistance measurements with a Rotchschild R-1020 static voltmeter (Zurich, Switzerland). Two fabric specimens (10 mm × 100 mm) 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 direct current source. The elapsing time [t (s)] was defined as the time required for discharging half of the charge present in the specimen. The resistance [R (Ω)] of the specimen was calculated as follows:

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

Conductivity properties

A DT9205 digital multimeter with accuracy ±1.0% (Hong Kong, China) was used for the conductivity measurements. Random areas (50 mm × 50 mm) from both the front and back surfaces of the silver-plated fabrics were measured.

Antibacterial measurements

The antibacterial properties of the fabrics were investigated through the incubation of bacterial solutions of both *Escherichia coli* and *Staphylococcus aureus* with 10^8 CFU/mL densities at 37°C for 18–24 h.

Surface observations

The surfaces of the silver-plated fabric structures were studied with a JSM-6335F field emission scanning electron microscope (Tokyo, Japan). The scanning electron microscopy (SEM) images of the surfaces were taken at a magnification of 30,000×.

RESULT AND DISCUSSION

Effect of chemical silver plating on the fabric weight, thickness, and bending properties

The measurements of the changes in the weight, thickness, and bending after the chemical-plating treatments of the two fabrics are shown in Table III. The weights of the two silver-plated fabrics were heavier than those of the untreated ones. The measured weight increases were 11.1 and 16.67% for the cotton and polyester specimens, respectively. That the silver-plated fabrics were heavier than the original ones showed that silver ions had clung to the surfaces of the fabrics effectively.

As for the thickness, the cotton and polyester fabrics experienced only small changes, 0.02 and 0.01 mm, respectively, after they were subjected to a series of chemical treatments.

The results proved that the chemical-plating solutions reacted with the original fabrics during the entire process of both acid sensitization and alkaline plating. As for the handle of the plated fabrics, the bending results indicated that the silver-plated polyester fabric became softer than the original one, whereas the sil-

TABLE IV
Color Changes Under Different Application Conditions

Specimen	Laundering	Perspiration		Rubbing		Light
		pH 5	pH 8	Dry	Wet	
Silver-plated cotton	4	4–5	4–5	3–4	1–2	4–5
Silver-plated polyester	4	4–5	4–5	2	2	4–5

TABLE V
Measurement of the Color Appearance for the Silver-plated Fabric

	CIE data (D65/10°)					
	L^*		a^*		b^*	
Specimen	Original	Silver-plated	Original	Silver-plated	Original	Silver-plated
Cotton	85.23	41.83	−0.09	2.45	0.22	10.16
Polyester	89.27	57.43	0.61	0.49	5.81	12.43

ver-plated cotton fabric had a stiffer handle than the original one.

Color change assessment

The results of the color changes under different application conditions (washing, perspiration, rubbing, and light) are shown in Table IV. For the silver-plated cotton and polyester fabrics, the colors slightly changed after washing; that is, the tested specimens were paler than the original silver-plated specimens. This confirmed that some silver particles were lost during washing.

The rubbing fastness of the silver particles in the fabrics is shown in Table IV. Under dry-rubbing conditions, the degrees of staining for the silver-plated cotton and polyester fabrics were 3–4 and 2, respectively. The silver-plated cotton fabric had better dry-rubbing fastness than the silver-plated polyester. On the other hand, the opposite results were found for the wet-rubbing fastness; that is, the silver-plated polyester fabric (grade 2) had better wet-rubbing fastness than the silver-plated cotton fabric (grades 1–2). On the basis of the overall results of the rubbing-fastness measurements, the rubbing fastness of the silver-plated fabrics was poorer than commercial requirements.

The light fastness for both the silver-plated cotton and polyester fabrics was 4–5; this was considered good and could meet the commercial requirements of light fastness for vision. This showed that the silver-plated cotton and polyester fabrics were capable of resisting artificial light under the prescribed conditions of a simulated light climate. Hence, these silver-plated fabrics were quite stable under normal lighting conditions.

Color measurements

Cotton changed from white to brownish grey after the silver-plating treatment. However, polyester did not change in appearance after the silver-plating treatment. This could imply that it tolerated the conditions of both acid and alkali solutions during the plating treatment.

Table V shows the color appearance of the silver-plated fabrics. For the brightness measurement, all the silver-plated fabrics had lower values than the original fabrics. They were considered grey after the plating treatment. Because the alkali-plating solution attacked the white fabrics and made them brown, the resultant color meant positive a^* and b^* values for cotton. The silver-plated cotton fabric had higher values of a^* and b^* than the original cotton fabric, which was reddish yellow. On the other hand, the silver-plated polyester fabric had a lower value of a^*, and this indicated that there was a change to a greenish color. This might have been due to the strong effect of the silver particles on the surface of the specimen. Every sample became more grey after the silver-plating process, as shown by the lower L^* values. The polyester fabric was more silver-grey. On the contrary, the cotton fabric showed less of a silver effect. On the basis of the testing results, the cotton and polyester fabrics produced different results.

UV radiation penetration measurements

Table VI summarizes the measurements for the UV radiation penetration. The results showed that the original cotton fabric was not appropriate for protecting against UV radiation, as indicated by the ultraviolet radiation penetration factor (UPF) rating of 10. However, the

TABLE VI
Measurement of UPF

	Calculated UPF		UPF rating	
Specimen	Original	Silver-plated	Original	Silver-plated
Cotton	13.48	219.36	10	50+
Polyester	101.74	488.38	50+	50+

TABLE VII
Fabric Measurements During Static Half-Life Testing for the Silver-Plated Fabric

	Average (s)			
	Warp		Weft	
Specimen	Original	Silver-plated	Original	Silver-plated
Cotton	0.6	0.5	0.8	0.5
Polyester	694	128	712	128

TABLE VIII
Conductivity Measurements of the Silver-Plated Fabric

	Average resistance (Ω)	
Specimen	Original	Silver-plated
Cotton	6.310×10^6	504
Polyester	1×10^{14}	16

chemical-plating results confirmed that the silver-plated cotton offered excellent protection against UV radiation, as indicated by the UPF rating of 50+.

On the other hand, the silver-plated polyester fabric could reduce UV transmission better than the original polyester. On the whole, all the silver-plated fabrics could improve protection against UV radiation with excellent results.

Determination of the static half-life and measurement of the electrical resistance

As shown in Table VII, the average static half-life value of the silver-plated cotton was almost null in both the warp and weft direction, and this was considered evidence of good antistatic properties due to the silver plating. On the other hand, the silver-plated polyester fabric had a reduced value of the static half-life. This was shown by the time drop from 693.8 to 128.1 s in the warp direction and from 712.5 to 127.5 s in the weft direction in comparison with the original fabric. The smaller the static half-life was, the better the enhancement was of the prevention of static charge for both the cotton and polyester fabrics. Hence, the silver-plating treatment could improve the antistatic properties.

The conductivity responses of cotton and polyester are illustrated in Table VIII. Both cotton and polyester developed the conductivity properties after the silver-plating treatment. The resistance of cotton and polyester was changed from 6.31×10^6 and 1×10^{14} to 504 and 16 MΩ, respectively. The results of electrical resistance for the silver-plated fabrics could explain the significantly reduced static charges on two fabrics.

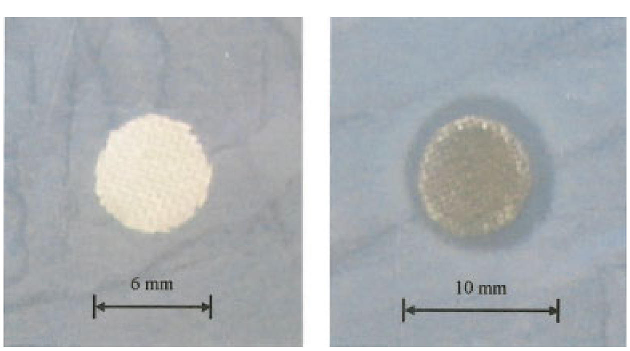

Figure 1 Inhibition zone with *E. coli* bacterium in the original (left) and silver-plated cotton fabrics (right).

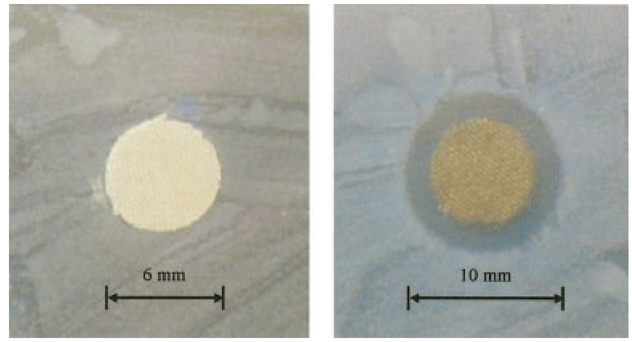

Figure 2 Inhibition zone with *E. coli* bacterium in the original (left) and silver-plated polyester fabrics (right).

Antibacterial properties

The surfaces of the silver-plated cotton and polyester fabrics were covered with a nutrient medium in which a culture of test *E. coli* (Figs. 1 and 2) or bacterium *S. aureus* (Figs. 3 and 4) had been spread to produce uniform growth under cultured conditions at 37°C for 18–24 h.

The silver-plated treated cotton and polyester fabrics (Figs. 1–4) were very effective against the two bacteria, as shown by the appearance of clear halos around the plated specimens. The calculated resistant diameter scales are tabulated in Table IX.

The larger the change was in the antibacterial areas, the more effective the antibacterial properties were. The experimental results showed that the two kinds of fabrics exhibited similar antibacterial properties, and so it was concluded that the silver-plating treatment could impart antibacterial properties to the tested fabrics.

Surface structure measurements with SEM

For greater insight into the changes in the surface properties of the fibers, the fabrics were examined with SEM. The results showed that the silver-plated fibers were covered by silver particles uniformly. The

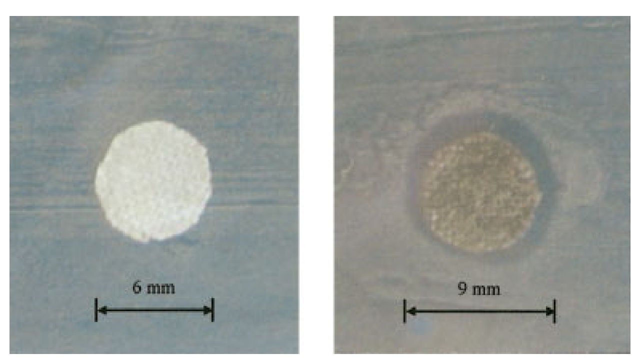

Figure 3 Inhibition zone with *S. aureus* bacterium in the original (left) and silver-plated cotton fabrics (right).

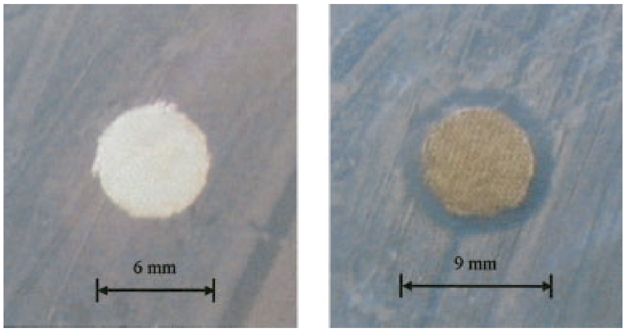

Figure 4 Inhibition zone with *S. aureus* bacterium in the original (left) and silver-plated polyester fabrics (right).

pictures taken by SEM are shown in Figures 5–8 (original magnification = 30,000×). The grain diameters of the metal particle aggregates ranged from 30 to 100 nm. A detailed view of a photomicrograph indicated that the plated layer was composed of a mass of particle cluster zones evenly distributed on the surfaces of the fibers. The surfaces of both the cotton and polyester fibers were covered with dense silver particles, which were clearly visible. This indicated that the effect of chemical silver plating was sufficient and effective enough to change the microstructure of the cotton and polyester fibers.

Figures 5 and 6 show SEM pictures of the untreated and silver-plated surfaces of the cotton fiber, respectively. The SEM pictures of the polyester fabric surface before and after chemical silver plating are shown in Figures 7 and 8. There was no continuity of metal particle aggregation in the polyester fibers. The lamination effect of the chemical silver plating was significantly shown by the regular covering of the silver particles on the fiber surface.

Overall analysis

The cotton and polyester fabrics, after chemical silver plating, had unique characteristics. According to SEM, chemical silver plating rendered uniform silver particles on both the cotton and polyester fabrics. This method could be employed for the uniform metalization of nonconductive fabrics. For the successful deposition of plating, only autocatalytic reactions could be used. This investigation demonstrated that chemical silver plating could produce decorative and functional fabrics, and the normal quality of the fabrics was maintained. The experimental results showed that the fabrics plated with silver had better properties, including protection against UV radiation penetration, light fastness, antistatic properties, and antibacterial properties. Such special abilities were due to the fact that the basic silver particles had greater shielding properties and better conductivity than the original fabrics. According to the testing results, chemical silver plating only imparted moderate rubbing-fastness properties to the cotton and polyester fabrics. Comparatively, the fastness of thin-sheet silver depended on the surface structure of the original fabric. The thin silver particles had better fastness than the thick ones. For

TABLE IX
Calculated Diameters of the Antibacterial Areas

	Diameter (mm)			
	E. coli		*S. aureus*	
Specimen	Original	Silver-plated	Original	Silver-plated
Cotton	6.0	10.0	6.0	9.0
Polyester	6.0	10.0	6.0	9.0

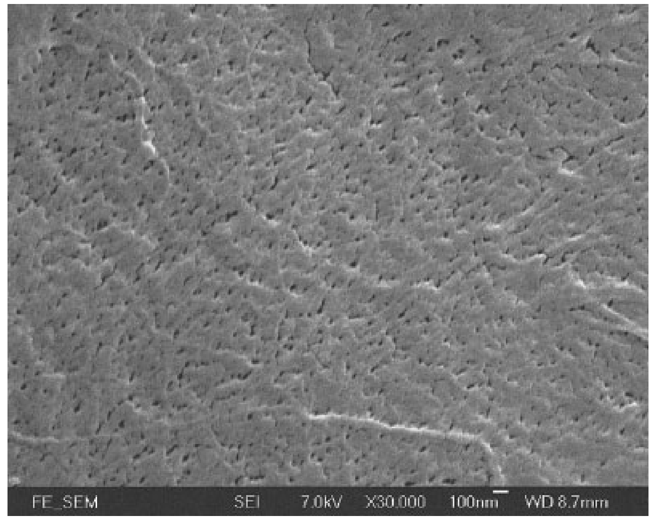

Figure 5 Surface appearance of the original cotton fiber (SEM with an original magnification of 30,000×).

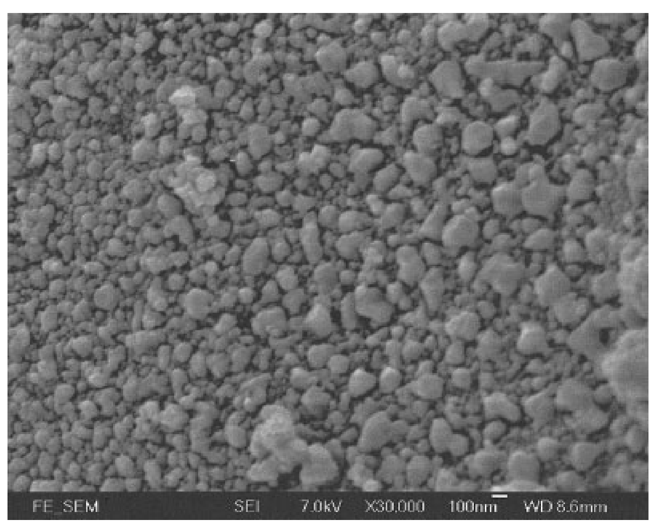

Figure 6 Surface appearance of the silver-plated cotton fiber (SEM with an original magnification of 30,000×).

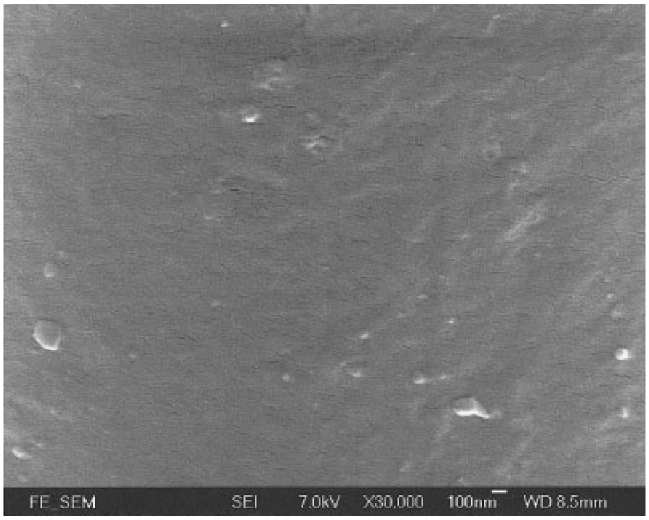

Figure 7 Surface appearance of the original polyester fiber (SEM with an original magnification of 30,000×).

good fastness of silver particles on fabrics, the proper control of the ratio of the chemical-plating solution, the development of the pretreatment for the surfaces of fabrics, and the selection of appropriate fabrics must be mastered.

Design applications

The silver-plating process certainly covered and changed the appearance of the standard cotton and polyester fabrics. A silvery-grey color imparted luster to the face and back of the textile specimens with a fluid handle. The silver appearance was based on the thickness of the silver-plated particles, which combined different ratios of the composition with respect to various parameters, including the solution concentration, temperature, and reaction duration. The experiments with chemical silver plating showed that the reflected abilities were higher on the smooth surface of polyester than on the rough surface of cotton. On the other hand, the cotton fabric became grey with brown during the plating treatment.

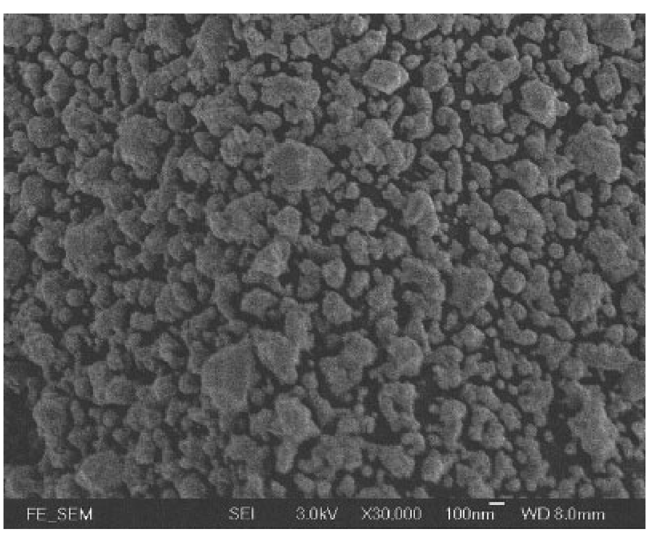

Figure 8 Surface appearance of the silver-plated polyester fiber (SEM with an original magnification of 30,000×).

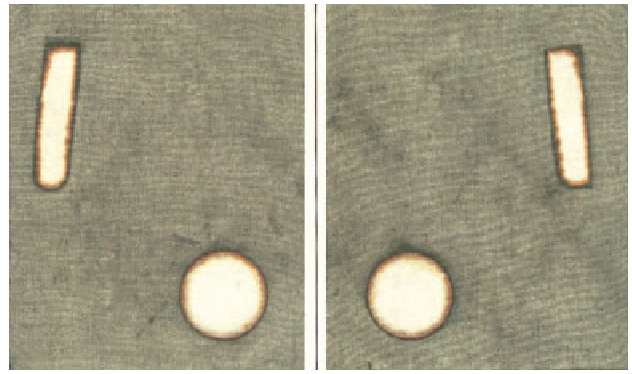

Figure 9 Front (left) and back (right) of silver-plated cotton with resistance crafts.

As previously mentioned in this design study, the resistance crafts permitted a certain degree of randomization. As in the design operation, the pattern could be created with a physical resist method on the surfaces of the cotton and polyester fabrics. Many complementary materials, such as pastern strips, metal pieces, clips, wooden sticks, and glass plates, were employed to resist the silver-plating reaction to generate various patterns on the fabrics. This method could easily achieve the goal of creating patterns on experimental fabrics by silver plating. Tabby cotton and polyester fabrics were launched with this series of design practices. The colorful design results with resistance crafts could isolate the activity of the plating reaction at the special areas. There were many design outcomes that had unique effects with chemical silver plating and connecting resistance crafts, as shown in Figures 9 and 10. Furthermore, there were many different effects applied to the freedom structure and agile operation. For example, the results were applied to textile finishing to create different effects on the sensitization action and the plain patterns in chemical-plating action. Similar patterns had blurred resistance shapes and subtle brown colors on cotton fabrics in both the front and back, as illustrated in Figure 9. The brown aureolas were stained when a cotton sample was pretreated with ammonium in a sensitization solution. On the other hand, Figure 10 shows a clear edge on both the smooth surface and dense structure of the polyester fabric. The influence of the pretreatment solution did not appear in the surface of the black polyester.

From the preliminary design experiments, some conclusions were drawn: (1) the final color appearance

Figure 10 Silver-plated polyester with resistance crafts.

depended on the properties of the fabric substrates, (2) the diverse appearances could be managed through the control of the reaction timescale, (3) this reflected value correlated with the concentration of the solution, (4) the resistance crafts could shield the plating reaction and lead to metalizing fabric creation, (5) the patterns could be generated in the fronts and backs of fabrics uniformly, and (6) the influence of the chemical solutions needed to be considered in operation.

These designs from chemical silver plating showed that the surface characteristics of the fabrics were sensitive enough to load the silver particles onto the cotton and polyester fabrics. A variety of images with unique colors, patterns, and textures were achieved after chemical silver plating was conducted on the surfaces of the fabrics. They could produce silvery effects with shimmering color on the polyester fabric. There is boundless potential, which depends on the control of the resist shape and the operational manner, in metalizing textile applications.

CONCLUSIONS

The overall experimental analysis and results did help in developing chemical silver plating for standard fabrics. Two kinds of nonconducting fabrics, cotton and polyester, were plated by chemical silver plating. Each combination of a metal and a reducing agent required a specific pH range and bath formulation.

In comparison with other metalizing methods, chemical silver plating has the following advantages: (1) nonconducting fabrics can be metalized to create design patterns; (2) the operation can be controlled through the adjustment of the contribution of the chemical-plating solution; (3) silver particles are uniform with dense granules; and (4) many functions can be improved, such as the antibacterial properties, antistatic properties, and UV penetration shielding.

According to the design results, the silver-plated fabrics showed several advanced images. Theoretically, chemical silver plating could provide an immediate unique appearance and technical finishes on many kinds of fabrics, such as cotton and polyester, resulting in the generation of many textile designs. For decorative features of fabrics, a significant correlation exists between the metalization and design concept. On the basis of this experimental study, it is obvious that chemical silver plating can also be used for unique textile design applications, such as reflecting surfaces, silver color, and smooth textures, as well as functional fabric.

References

1. Smith, W. C. J Coat Fabrics 1999, 28, 292.
2. McCarty, C.; McQuaid, M. Structure and Surface: Contemporary Japanese Textile; Museum of Modern Art: New York, 1998.
3. Braddock, S. E.; O'Mahony, M. Techno Textiles Revolutionary Fabrics for Fashion and Design; Thames and Hudson: London, 1999.
4. Higgins, J. P. P. Cloth of Gold, a History of Metallised Textiles; Lurex: London, England, 1993.
5. Bertuleit, K. J Coat Fabrics 1991, 20, 211.
6. Brenner, A.; Riddel, G. E. J Res Nat Bur Stand 1946, 37, 31.
7. Vaskelis, A. In Coatings Technology Handbook; Statas, D., Ed.; Marcel Dekker: New York, 2001.
8. Othmer, K. Encyclopaedia of Chemical Technology, 4th ed.; Wiley: New York, 1995; Vol. 9.
9. Zeng, H. L. The Handbook of Electroplating Technology; Mechanical Industry: Beijing, 2002.