

Agent Distribution and Water Remaining of Polyester Nonwoven Fabrics After-Treated with Polyurethane–Citric Acid

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ABSTRACT: Polyester nonwoven fabric samples were used to treat with aqueous solutions of water-soluble polyurethane (PU) containing the foaming agent, citric acid, or the mixtures of foaming agent and citric acid to examine the water remaining and the degradation of PU under the simulative condition of under ground. The results reveal that the viscosity of PU solutions could affect the values of pickup and add-on. The water remaining values for PU containing citric acid are higher than those for PU containing the foaming agent and PU containing the foaming agent and citric acid. The pore structures, nonwoven construction, and the pores caused by the aggregation of PU within/on the

treated nonwoven fabrics can affect the water remaining. From the observation of SEM and the comparison of FTIR, the degradation of water-soluble PU resin is proved, which could form the rough porous surface of PU resin on the fiber surface as a factor improving the water remaining. The value of water remaining for PU containing citric after 60 weeks' treatment is significantly higher than the pristine nonwoven fabric (control). © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 100: 47–56, 2006

Key words: degradation; FTIR; polyurethane; nonwoven; water remaining

INTRODUCTION

The nonwoven fabric used in land engineering needs the special function of water permeation. In general, there are three main layers in the soil-retaining layer. The first main layer is composed of the original soil structure, filter zone, and filter cake. The third main layer is the revetment. The layer between the two main layers is the nonwoven geo-textile,^{1–3} which is used to retain the soil, but lets the water to pass through to prevent the happening of landslide. There are many factors that could affect the physical and water remaining properties of the geo-textiles or geomembranes, such as temperature, pressure, surface of fibers (materials), and manufacturing effects.^{4–12} Shan et al.⁶ and Palmeira and Gardoni⁷ studied the hydraulic behavior of nonwoven geo-textiles soiled by clay and sand. Hwang et al.⁵ pointed out that the water permeability coefficients for the needle-punched staple were different from that for the continuous filament nonwoven fabrics. Others^{10,11} studied the degradation of geo-textiles and the drainage of water.¹⁰

One interesting field for the use of nonwoven fabric is the arboricultural engineering, such as planting of vegetation. Wang¹³ pointed out that the well structure

of vegetation planting block could improve the growth of vegetation. This structure of vegetation planting block was formed with five layers. Those layers were original soil, first nonwoven, grid of plastic, second nonwoven, and soil containing small stone particle layers. The grid of plastic layer was used as drainage. The roots of the vegetation on the soil layer will penetrate through the first nonwoven fabric layer and also through the second nonwoven layer. If the nonwoven layer is a highly hydrophobic layer, the penetration of the roots of the vegetation will be undesired. The higher water remaining property and larger pore structure of the nonwoven layer, which provides the more suitable environment for the penetration of the roots of vegetation, will have the higher benefit for the up-growth of vegetation on the layer of original soil. In general, the methods for improving the water remaining of polyester (PET) nonwoven fabrics were the blending of hydrophilic cellulose fibers to PET fibers or the addition of hydrophilic surfactant onto the surface of the PET fibers. However, the former has significant decreasing effect on the strength of the nonwoven fabrics and the latter has only the temporary effect. In another case, the use of alkali agents could hydrolyze PET fibers to create the rough pore on the fiber surface, but they decrease the strength of nonwoven fabric significantly. In this study, we expect that the pad-baking after-treatment of the aqueous solutions of water-soluble polyure-

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thane (PU) can improve the water remaining properties of the treated PET nonwoven fabrics and have no effect on the strength of the nonwoven fabric. From careful selection of the specification of nonwoven fabrics accompanied by the suitable treating conditions, we expect that because of to the degradation of water-soluble PU molecules on the surface of PET fibers caused by the combination of citric acid, the water remaining ability will be increased after a longer time period of using.

However, the detailed information about the modification of fiber surface or pore structures of nonwoven by using after-padding treatment with aqueous solutions of water-soluble PU containing citric acid is lacking. In this study, the various concentrations of water-soluble PU containing various amounts of citric acid will be applied onto the fiber surface of the nonwoven with pad-baking process to study the values of water remaining, pore structures, and agent distribution of the after-treated PET nonwoven fabrics and the degradation of water-soluble PU in the presence of citric acid at 50°C and 90 RH%, which is the simulation of the practical condition under ground, will also be investigated by using fourier transform infrared spectroscopy (FTIR) and scanning electron microscope (SEM).

EXPERIMENTAL

Materials

In this study, we used the PET nonwoven fabric weighted 350 g/m². The polyester fiber was about 3 denier and 51 mm long. One side of the nonwoven fabric was melting treatment to match the standard of CNS 1128 A2183. This nonwoven fabric passed the determination of the method of 5610 L3080. It meets the standard level of 60 kg.

The foaming agent (CELLMIC CAP) was supplied by Sankyo Co. Ltd., Tokyo, Japan. Citric acid was obtained from Nihon Shiyaku Reagent, Tokyo, Japan. Water-soluble PU (45% solid content) was obtained from Nan Pao Resins Ltd., Taipei, Taiwan. Other reagents were all chemical grade.

After-treatment of nonwoven fabrics

PET nonwoven fabric samples were padded twice under 2.0 kg/m² to have an even pickup with freshly prepared aqueous solutions of PU (10 wt % PU containing different wt % of foaming agent, citric acid, or the mixtures of foaming agent and citric acid). The pH value of the PU aqueous solutions containing the foaming agent was adjusted to 4.5 with acetic acid to improve the foaming property. The viscosity values of the samples were measured with viscosity meter (LVT T4, Brookfield, Brookfield Engineering Laboratories,

Inc., MA) at room temperature under 30 rpm before padding. Padded fabric samples were baked at 135°C for 30 min, then washed with tap water to wash out the unfixed PU resin, and finally dried.

Observation of optical microscope and scanning electron microscope

To confirm the distribution of water soluble PU within/on the treated nonwoven fabrics, the PET nonwoven fabric samples were padded with higher concentration of PU aqueous solutions (20 wt % PU containing 4 wt % of foaming agent, 4 wt % of citric acid, or the mixtures of 2 wt % foaming agent and 4 wt % citric acid), containing 1 wt % of C.I. Direct red 111, baked under 135°C for 30 min, and then were washed and dried. The distribution of PU on the surface and the cross section of the treated nonwoven fabrics were observed with optical microscope PME (Olympus Optical Co. Ltd., Tokyo, Japan) and SEM S-2600H (Hitachi, Tokyo, Japan). The PU resin adhered on the fiber surfaces were observed with LEO 1530 Field Emission Scanning Electron Microscope (SEM, LEO-1530 Schottky FESEM, Oberkochen, German). The direct red dye was experimented and selected to stain PU resin for the convenience of observation.

Water remaining and add-on test

The values of water remaining of the treated fabrics were determined using the method of CNS L3233.

The values of add-on were calculated by the following equation.

$$\text{Add-on (\%)} = [A - B/B] \times 100\% \quad (1)$$

where, the values of A and B are the weight after and before treatment, respectively.

Fourier transform infrared spectroscopy (FTIR)

Infrared spectra of the samples were obtained using a KBr disk technique.¹⁴ Samples were prepared to give a dry weight of about 1.8 mg after storage in 1-dram vials over P₂O₅ for 3 days. Spectral-grade KBr (250–300 mg) was ground, transferred to individual sample vials, dried in an oven at ~200°C for several hours, and stored in an oven at 110°C. The aqueous solutions of (a) PU, (b) mixture of PU and citric acid (weight ratio is 5 : 1) were coated on a piece of glass, baked at 135°C. Another aqueous solution of (c) mixture of PU and citric acid (weight ratio is 5 : 1) was coated on a piece of glass, baked at 135°C, and then dried at 50°C, RH 90% for 60 weeks. Those samples were removed from the glass, dissolved in acetone, mixed and ground with KBr, and then pressed in an evacuated die under suitable pressure. Fourier transform infra-

TABLE I
The Values of Pick-Up, Add-On, and Times of Water Remaining for the PET Non-Woven Fabrics Treated with PU Solutions Under 135°C for 30 min

PU	Agent conc.(%)		Viscosity (mPa s)	Properties		
	Foaming agent	Citric acid		Pick-up (%)	Add-on (%)	Water remaining (%)
Control	—	—	1.0	0	0	5.20
10	0	0	2.0	80.7	5.8	1.03
10	0.3	0	2.0	95.4	7.1	1.21
10	0.5	0	1.8	118.3	10.1	1.32
10	1.0	0	1.6	137.2	12.2	1.41
10	2.0	0	1.5	150.5	14.3	1.50
10	0	0.3	1.8	88.5	6.2	1.15
10	0	0.5	1.7	88.7	6.5	1.54
10	0	1.0	1.6	89.8	6.9	1.89
10	0	2.0	1.6	92.8	7.7	2.01
10	1.0	0.3	—	140.2	13.4	1.42
10	1.0	0.5	—	148.5	13.4	1.99
10	1.0	1.0	—	153.2	14.3	2.61
10	1.0	2.0	—	155.3	14.6	2.87

red spectrophotometer (Jasco model FT/IR-3, Tokyo, Japan) was used to obtain the spectra.

RESULTS AND DISCUSSION

Pore structures and agent distribution

The PET nonwoven fabric samples were treated with the finishing solutions. Those were the aqueous solutions of water-soluble PU containing (a) foaming agent, (b) citric acid, and (c) the mixtures of foaming agent and citric acid with different weight percentages, respectively. The values of pickup, add-on, and the water remaining percentages of the treated nonwoven fabrics listed in Table I shows that the values of pickup and add-on are increased with the increase of foaming agent and citric acid used, especially the foaming agent. Higher pickup value has higher add-on value, which is a reasonable phenomenon [Fig. 1(a)], but the phenomenon that higher amount of foaming agent and foaming agent/citric acid has significantly higher pickup and add-on values is somewhat singularity. From the viscosity values of the different PU aqueous solutions listed in Table I, we can find that the pickup and add-on values have increased with the decrease of viscosity values of the PU solutions. It is thought that PU solution having the lower viscosity will have the higher penetration ability of agent into the gaps between the PET fibers of nonwoven fabrics to increase the values of pickup and add-on.

Table I also shows that the water remaining percentages have increased with the increasing amounts of foaming agent, citric acid, and foaming agent/citric acid contained in PU solutions. To realize the effect of water-soluble PU resin on the water remaining, the

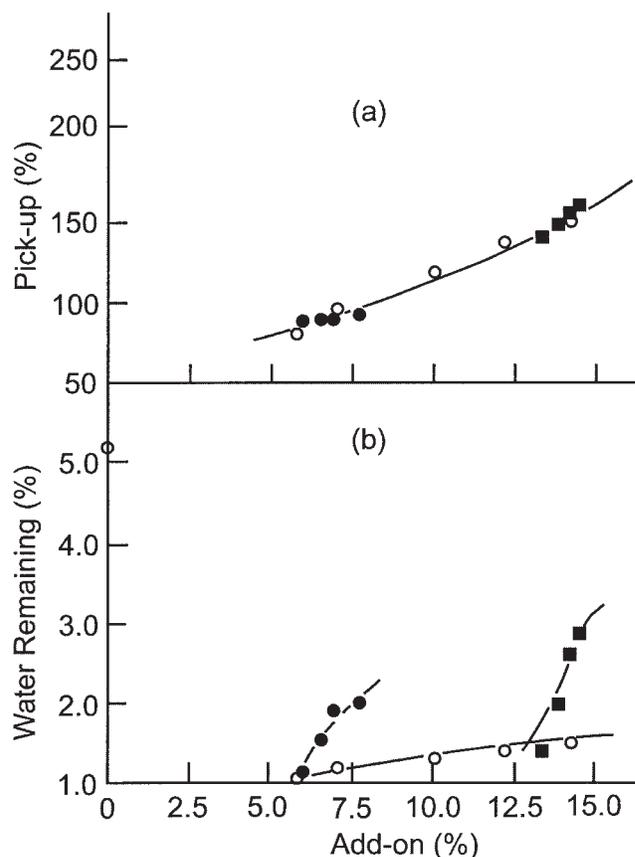


Figure 1 The relationships between (a) the values of pickup and add-on and (b) the water remaining improved percentage and the add-on of the water-soluble PU treated nonwoven fabrics, which contained (○) foaming agent, (●) citric acid, and (■) the mixtures of foaming agent and citric acid with different weight percentages, respectively.

relationships between the water remaining percentages and the add-on values of the different treated nonwoven fabrics are plotted in Figure 1(b). From the relationships in this figure, we can find that the water remaining percentages have gradually increased with the increasing add-on values for PU containing foaming agent. However, those data are significantly lower than that of the control. The latter may be caused by the block of water-soluble PU within the treated nonwoven fabrics; the former is surely attributed to the pore structure and agent distribution caused by different amounts of foams formed from different amounts of foaming agent under baking, that is, the gas foams created by the degradation of foaming agent, which may push the PU resin to adhere on the fiber surface to change the pore structure and the values of add-on. In addition, Figure 1(b) also shows that the values of water remaining percentages are significantly increased with the increasing add-on values for PU containing different amounts of citric acid in both the systems of PU and PU/foaming agent. The higher amount of citric acid used is thought to change the zeta potential¹⁴ of PU resin to enhance the adhesive ability onto the PET fiber surface to slightly increase the values of add-on and significantly increase the values of water remaining percentages for other factors such as pore/agent distribution beside the higher hydrophilic functional groups of citric acid.

In this study, we expect that the amide foaming agent will degrade at about 130°C to create the foams within PU resin to change the pore (capillarity) and distribution of PU within/on the treated nonwoven fabrics. For water-soluble PU, the foams will create the pore spaces, which can connect together to form the continuous pores, allowing the water remained within nonwoven fabrics. If the expectation of our original concept is true, we will find pores formed by PU within nonwoven fabric or other distribution changes of PU on the treated nonwoven fabrics. To confirm this concept, the surface structure of the treated nonwoven fabrics ($\times 10$) for (a) control, (b) 20 wt % PU, (c) 20 wt % PU and foaming agent (4 wt %), (d) 20 wt % PU and citric acid (4 wt %), and (e) 20 wt % PU and foaming agent (2 wt %) and citric acid (4 wt %) are examined and shown in Figure 2(a–e), respectively. The higher concentration of PU used in this section was for the purpose of convenience in observation.

As compared with Figure 2(a,b), the surface of the untreated and PU-alone treated nonwoven fabric, respectively, it can be found that the PET fibers on the surface of PU alone treated nonwoven fabrics are adhered with water-soluble PU and the fiber construction on the surface of the treated nonwoven fabric is similar to that on untreated fabric. From the nonwoven construction on the surface of the treated and untreated nonwoven fabric, we can find that the existence of water-soluble PU on the fiber surface will

decrease the water remaining values. Figure 2(c,e), show that no pore existed on/within PU resins for the sample containing the foaming agent. Those results may be caused by the viscid fluxion of PU resin during the baking process. That is, as the foaming agent was degraded to form the gas foams at about the temperature of 130°C within the PU resin, which was still on the state of viscosity; the foams, therefore, could not be retained within the matrix of PU resin for its higher mobility. The aggregation of PU resin on the surface of the treated nonwoven fabrics is caused by the migration of PU resin within the padded fabrics under the backing of high temperature (135°C). In such condition, the foaming agent was degraded to form the gas foams to enhance the migration effects of fluxional PU resin by the pushing force of formed gas. Rowland et al.^{15–19} pointed out that the crosslinking agents would migrate from the center of the padded fabrics to the outer part or surface of the treated fabrics under higher drying conditions. However, the aggregations of water-soluble PU on the surface of the treated nonwoven fabrics shown in Figure 2(c–e) do not decrease the water remaining values, but increases it. The higher water remaining values of the PU treated nonwoven fabrics (Table I), which have higher surface migration, could be attributed to that with higher hydrophilic surface of water-soluble PU containing citric acid or other structural factors.

There is a larger contact angle indexed as “E” in Figure 2(c) as compared with that in Figure 2(d,e). This phenomenon should have been caused by the more hydrophilic surface of PU containing citric acid, which has higher hydrophilic property than PU alone by because of the higher hydrophilic property of citric acid. Figure 2(e) shows the formation of PU films on the surface of PU containing the foaming agent and citric acid indexed as “F”. Those results suggest that the pores of the nonwoven fabric are partially blocked by the forming of PU film on the surface of the treated nonwoven fabrics to decrease the water permeability [Table I and Fig. 1(b)]. The films created in this condition may be caused by the turbulence of PU by the gas foams and the higher hydrophilic property of citric acid. The surface migration phenomenon of the treated nonwoven fabrics may be attributed to the “turbulence” and “aggregation,” respectively, for PU containing foaming agent and PU containing foaming agent/citric acid, as described in the previous section. From the discussions of the above three photographs, it can be found that the distribution of PU resin on the treated nonwoven fabrics can only affect the water remaining values in the finite degree. The distribution of PU within the nonwoven fabrics also plays an important role on the water remaining values, that is, the pore formed from gas foams in the PU matrix of the treated nonwoven fabric with PU containing the foaming agent, which could change the nonwoven con-

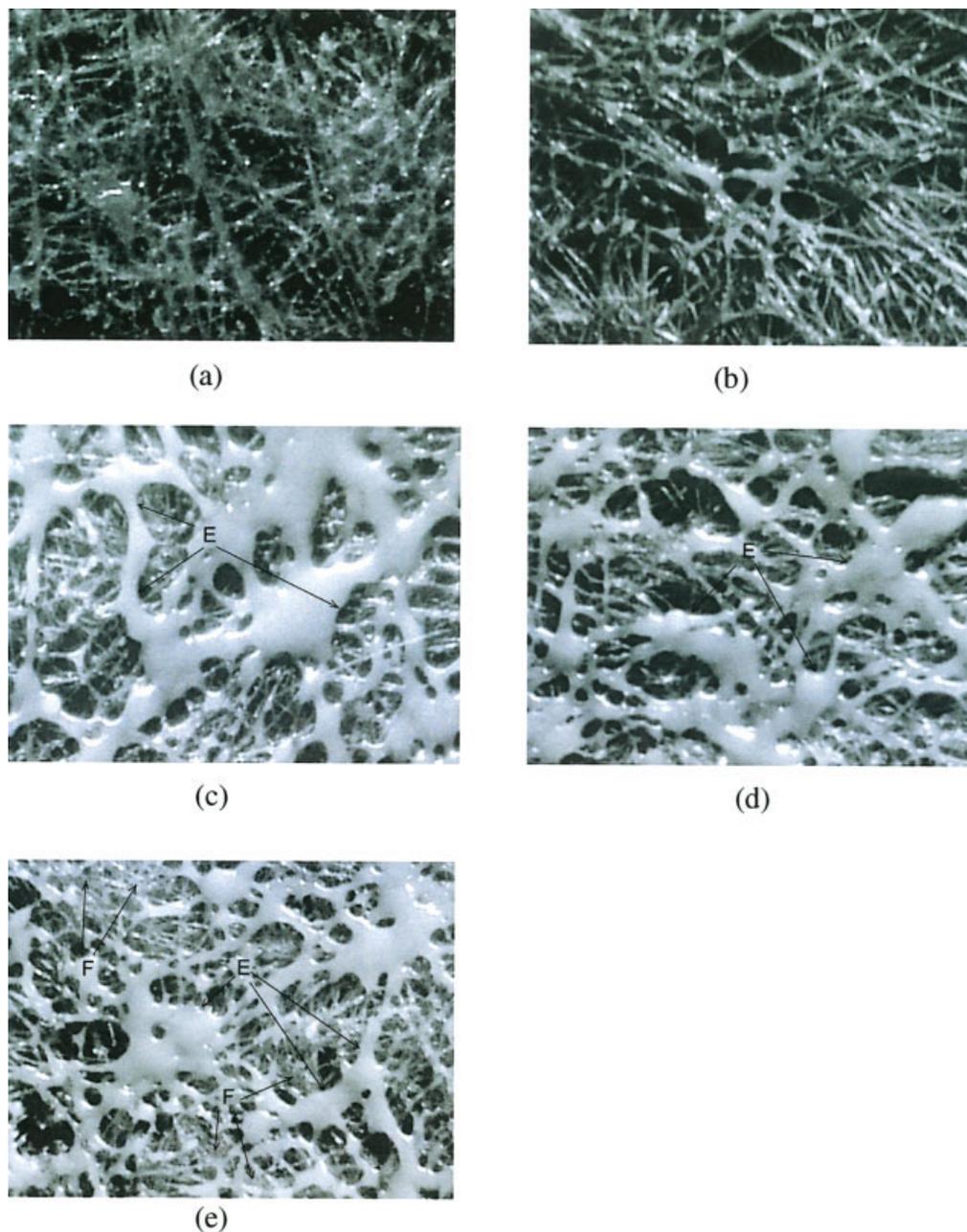


Figure 2 The photographs of the surface structure of the treated nonwoven fabrics ($\times 10$) for (a) control, (b) 20 wt % PU, (c) 20 wt % PU and foaming agent (4 wt %), (d) 20 wt % PU and citric acid (4 wt %), and (e) 20 wt % PU, foaming agent (2 wt %), and citric acid (4 wt %), respectively. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

struction or pore structure within the treated nonwoven fabrics.

The distribution of water-soluble PU within the treated nonwoven fabrics interested us to investigate. The photographs of the cross section of the treated nonwoven fabrics ($\times 40$) are shown in Figures 3(a)–3(d), respectively, for (a) 20 wt % PU alone, (b) 20 wt % PU and foaming agent (4 wt %), (c) 20 wt % PU and citric acid (4 wt %), and (d) 20 wt % PU and the mixture of foaming agent (2 wt %) and

citric acid (4 wt %). Figures 4(a)–4(d) show the photographs ($\times 100$) of the cross section of the same treated fabrics. From Figures 3(a) and 4(a), we can find that the PU resin is evenly adhered on the surface of the fibers of the PU-alone treated nonwoven fabric; however, the agents are aggregated within the pore between the fibers of the PU/foaming agent, PU/citric acid, and PU/foaming agent/citric acid, respectively, in Figure 3(b–d) and Figure 4(b–d).

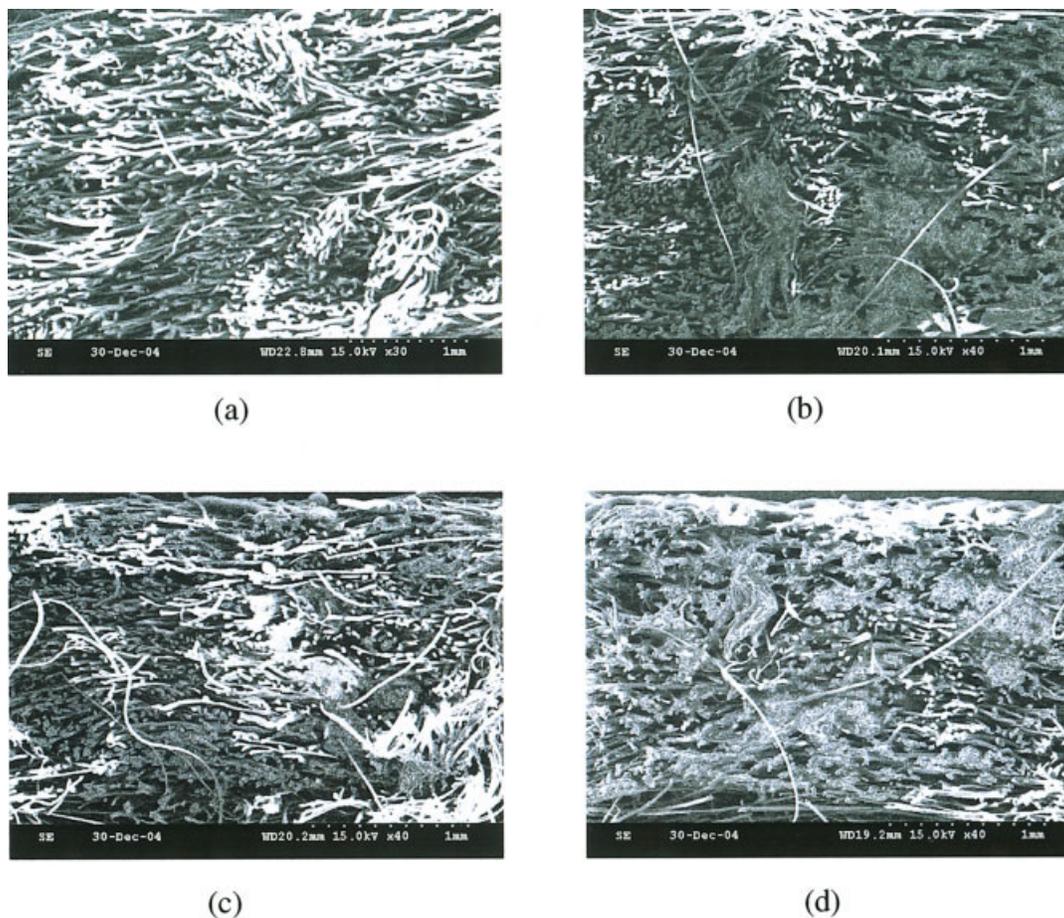


Figure 3 The photographs of the cross section of the treated nonwoven fabrics ($\times 40$), respectively, for (a) 20 wt % PU alone, (b) 20 wt % PU and foaming agent (4 wt %), (c) 20 wt % PU and citric acid (4 wt %), and (d) 20 wt % PU, the mixture of foaming agent (2 wt %), and citric acid (4 wt %). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Figures 3(b) and 4(b) clearly show that there are some big pores and cakes of aggregated PU existing, and the nonwoven construction has some disorders within the PU/foaming agent-treated nonwoven fabric. Within PU/citric acid treated nonwoven fabric, the pores and cakes of aggregated PU are smaller, but show more order than PU/foaming agent treated nonwoven fabric [Figs. 3(c) and 4(c)]. However, the pores become bigger but random; the number of cake of aggregated PU becomes more, and the nonwoven construction becomes more disordered within the PU/foaming agent/citric acid treated nonwoven fabric than that within the PU/foaming agent. Those figures show that the water remaining percentages are matched with the results shown in Table I for these three treated nonwoven fabrics. That is the water remaining is deeply affected by the pores, nonwoven construction, and the number of cake of aggregated PU within the treated nonwoven fabrics. On the other hand, those figures also separately match with the results of agent distribution on the surface shown in Figure 2(b–e), especially the phenomenon of the ag-

gregated cake of PU. Again, the discussions for Figure 2(a–e) are confirmed by the results of Figure 3(a–d) and 4(a–d).

The above results clearly show that the after-treatment of water-soluble PU will form a clog within the nonwoven fabrics to decrease the fine interstice between fibers and the water remaining values, but the hydrophilic surface of water-soluble PU containing citric acid and the pore structures caused by the disorder of nonwoven construction and agent migration will inversely increase the value of water remaining.

Degradation of water-soluble PU under the condition of simulation

Our original expectation is that the PU molecules will be degraded gradually to increase the hydrophilic functional group to complement the decrease of water remaining because of the clog of the pore of the nonwoven blocked by fine soil particles during uses. The condition of under ground is simulated as 50°C and 90 RH%. In this study, the above condition will be used

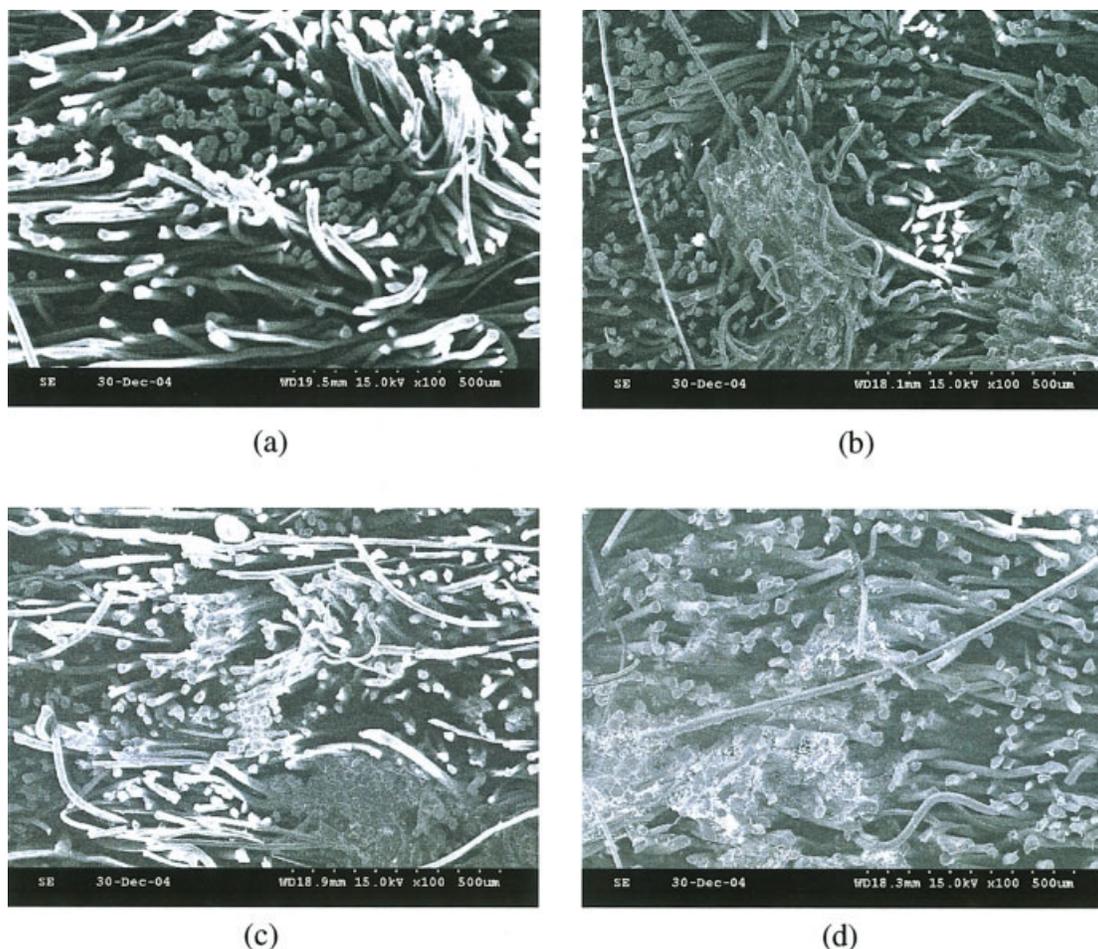


Figure 4 The photographs of the cross section of the treated nonwoven fabrics ($\times 100$), respectively, for (a) 20 wt % PU alone, (b) 20 wt % PU and foaming agent (4 wt %), (c) 20 wt % PU and citric acid (4 wt %), and (d) 20 wt % PU, the mixture of foaming agent (2 wt %), and citric acid (4 wt %). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

to examine the degradation of water-soluble PU resin adhered within the PET nonwoven fabrics. Table II shows the values of the changes of water remaining improved percentage for the nonwoven fabrics treated with PU solutions containing fixed amount of foaming agent, citric acid, and the mixture of foaming agent and citric acid at 135°C for 30 min and then baked under 50°C , 90% RH for various time periods. The

relationships between baking time periods and the changes of water remaining improved percentages plotted in Figure 5, showing that the values of the water remaining improved percentage have significantly increased with the increasing baking time period for all the three cases, except the pristine PET (control) nonwoven. This figure also reveals that the values of the water remaining improved percentages

TABLE II
The Changes of Water Remaining Improved (%) for the PET Non-Woven Fabrics Treated with PU Solutions Under 135°C for 30 min and then Baked Under 50°C , 90% RH for Various Time Periods

PU	Agent Conc. (%)		Changes of water remaining improved (%)			
	Foaming agent	Citric acid	3 weeks	10 weeks	30 weeks	60 weeks
Control	—	—	-15	+27	+32	+50
10	1.5	0	+56	+108	+262	+305
10	0	1.5	+118	+268	+441	+571
10	1.5	1.5	+94	+182	+335	+437

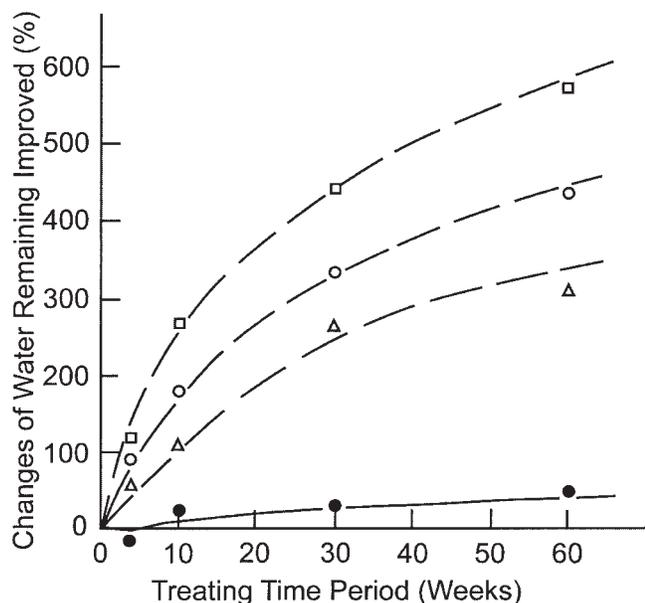


Figure 5 The relationships between baking time periods and the water remaining improved percentage for (Δ) 20 wt % PU containing 4 wt % foaming agent, (\square) 20 wt % PU containing 4 wt % citric acid, (\circ) 20 wt % PU containing 4 wt % foaming agent and 4% citric acid, and (\bullet) control sample.

for the various treated nonwoven fabrics are in the rank of PU–citric acid > PU–foaming agent–citric acid > PU–foaming agent at a same baking time period. Additionally, the longer the treating time period, the larger the difference of the water remaining improved percentage among those three cases. This phenomenon may be caused by the degradation of water-soluble PU resin in the presence of citric acid and the depletion of citric acid by foaming agent separately. It is well known that foaming agent could be degraded in the presence of citric acid. Meanwhile, it is interesting to find that the water remaining improved percentages for water-soluble PU containing citric acid after 60 weeks' baking is 5.71 times higher than that after 0 week' baking; however, that for pristine nonwoven fabric (control) is only 0.5 times. The water remaining improved properties for water-soluble PU containing citric acid are significantly higher than that for pristine nonwoven fabric after 60 weeks' baking. This result was probably caused by the degradation of water-soluble PU, which can create more hydrophilic groups, such as amine and carboxylic acid, to improve the water remaining property. It may also be caused by the change of the aggregated state of water-soluble PU adhered on nonwoven surface or within the nonwoven fabric. Additionally, the slight increasing of water remaining property for the pristine nonwoven fabric (control) was probably caused by the changes of the nonwoven construction after longer time periods of baking under higher humidity.

To confirm the degradation of PU at the simulative condition of under ground in the presence of citric

acid, the following spectra of PU under various conditions were examined. Figure 6(a,b) show that the patterns of the infrared spectra of the samples of (a) PU and (b) PU and citric acid (weight ratio is 5 : 1), which were all baked at 135°C for 30 min. The interesting and important absorbing bands of PU shown in Figure 6(a) are those at 1660 and 1626 cm^{-1} of amide group and 1240 cm^{-1} of ester group for baked PU resin.²⁰ After adding citric acid to PU solution, the ester group at 1240 cm^{-1} shifts to 1250 cm^{-1} for the baked PU resin [Fig. 6(b)]. This phenomenon could be due to the interaction between PU molecule and citric

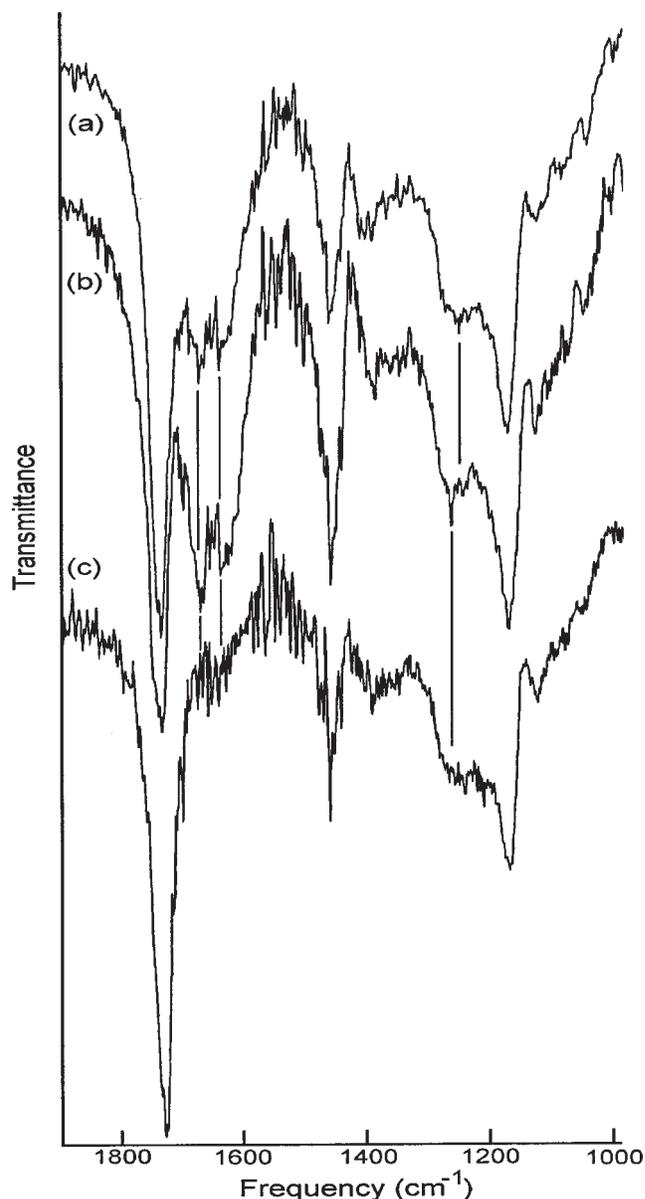
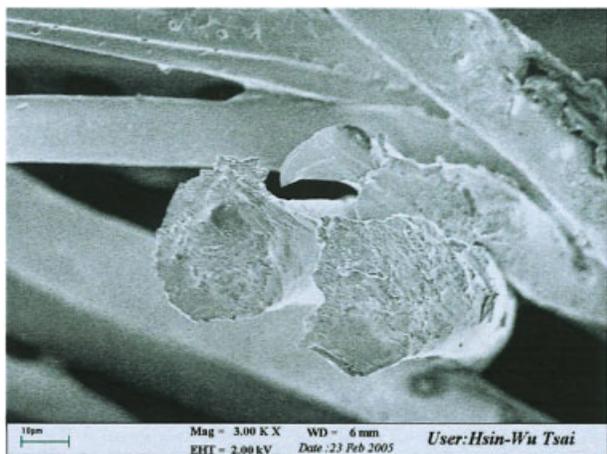
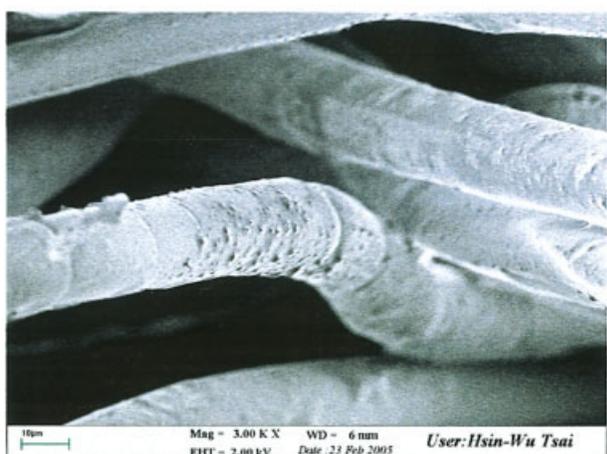


Figure 6 The infrared spectra of the samples of (a) PU and (b) the mixture of PU and citric acid (weight ratio is 4 : 1), which were all baked at 135°C for 30 min. The infrared spectra of the sample of (c) baked PU resin of (b), which was further baked at 50°C and 90 RH% for 60 weeks.



(a)



(b)

Figure 7 The photographs of the fiber surface ($\times 3000$) of the PU–citric acid treated nonwoven fabrics baking (a) under 135°C for 30 min and (b) under 135°C for 30 min and then 50°C and 90 RH% for 60 weeks. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

acid. However, as the baked PU resin of Figure 6(b) was further baked at 50°C and 90 RH% for 60 weeks, the amide group at 1660 and 1626 cm^{-1} and the ester group at 1250 cm^{-1} almost disappeared, as shown in Figure 6(c). Those results clearly show that water-soluble PU resin would be degraded under 50°C and 90 RH% for 60 weeks, the simulative condition of under ground, in the presence of citric acid.

Figure 7(a,b) are the photographs of the fiber surface ($\times 3000$) of the PU–citric acid treated nonwoven fabrics homologized Figure 6(b,c), respectively. Figure 7(a) shows the smooth surface of fibers, which was adhered with water-soluble PU resin for the sample baked at 135°C for 30 min. However, after the sample was further baked at 50°C and 90 RH% for 60 weeks, the surface of the fibers showed rough porous surface.

This phenomenon is clearly caused by the degradation of PU resin adhered on the surface of the fibers of the treated nonwoven fabrics. Again, water-soluble PU resin would be degraded under the 50°C and 90 RH% for 60 weeks, the simulative condition of under ground in the presence of citric acid was confirmed. The rough porous surface of water-soluble PU adhered on the fiber surface of the treated nonwoven fabrics could also be a factor that improved the water remaining property.

Figure 8 shows the photographs ($\times 10$) of the surface structure of the treated nonwoven fabrics with 20 wt % PU containing the mixture of foaming agent (2 wt %) and citric acid (4 wt %), which was baked at 135°C for 30 min and then further baked at 50°C and 90 RH% for 60 weeks. This sample (homologizing the sample of Fig. 2(e)) was selected for the clear change on the part of PU film formed on the treated and degraded nonwoven surface. There is a smaller contact angle indexed as “E” in Figures 8 as compared with that in Figure 2(c), but similar to that in Figure 2(e). The formation of PU films on the surface of PU containing the foaming agent and citric acid indexed as “F” shown in Figure 2(e) almost disappeared in Figure 8. From this figure, we can assure that the degradation has happened after 60 weeks’ baking.

The above results clearly show that the after-treatment of water-soluble PU containing citric acid will be degraded significantly under the simulative condition of under ground. This will increase the water remaining property caused by the higher hydrophilic groups, the rough porous surface formed of water-soluble PU adhered on the fiber surface, and the almost disappearance of PU film formed on the surface of the

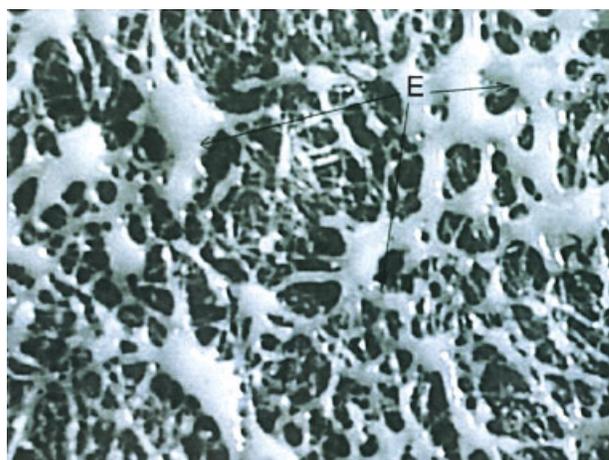


Figure 8 The photographs of the surface structure of the treated nonwoven fabrics ($\times 10$) for 20 wt % PU and foaming agent (2 wt %) and citric acid (4 wt %) under 135°C for 30 min and then baked under 50°C , 90% RH for 60 weeks. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

treated nonwoven fabrics. This result agrees with that of our original expectation. The water remaining values for water-soluble PU containing citric acid are significantly higher than that for pristine nonwoven fabric (control) after the longer time period of baking.

CONCLUSIONS

In this study, polyester nonwoven fabric samples were padded with aqueous solutions of water-soluble PU containing different wt % of foaming agent, citric acid, or the mixtures of foaming agent and citric acid to study the water remaining property of the treated fabrics and the degradation of PU under the simulative condition of under ground. The results show that the lower value of viscosity of PU solutions could have higher values of pickup and add-on. The water remaining percentages are deeply affected by the factors: (1) the nonwoven construction of treated nonwoven fabric, (2) the agent distribution on the surface of treated nonwoven fabric, and (3) the pores and cake caused by the aggregation of PU within the treated nonwoven fabrics. The changes of water remaining improved percentages for the various treated nonwoven fabrics are in the rank of PU–citric acid > PU–foaming agent–citric acid > PU–foaming agent after a same baking time period. Water-soluble PU resin would be degraded under the simulative condition of under ground in the presence of citric acid, which are confirmed with the observation of SEM and the comparison of FTIR, to form the rough porous surface of PU resin on the surface of fiber as a factor improving the water remaining.

References

1. Balkema, A. A. *Geosynthetics in Civil Engineering*; Balkema Publishers: Brookfield, MA, 1995; pp 53–56.
2. Peggs, I. D. *Geosynthetics: Microstructure and Performance*; ASTM: Michigan, 1990; pp 138–140, 150–161.
3. Koerner, R. M. *Designing with Geosynthetics*, 2nd ed.; Prentice Hall: New Jersey, 1990; pp 124–128.
4. El-Sadany Salem, H.; Dierickx, W.; Willardson, L. S. *Agric Water Manage* 1995, 27, 351.
5. Hwang, G. S.; Hwu, B. L.; Hsing, W. H.; Lu, C. K. *Geotext Geomembr* 1998, 16, 355.
6. Shan, H. Y.; Wang, W. L.; Chou, T. C. *Geotext Geomembr* 2001, 19, 509.
7. Palmeira, E. M.; Gardoni, M. G. *Geotext Geomembr* 2002, 20, 97.
8. Narejo, D. B. *Geotext Geomembr* 2003, 21, 257.
9. Iryo, T.; Rowe, R. K. *Geotext Geomembr* 2003, 21, 381.
10. Jeon, H. Y.; Kim, S. H.; Chung, Y. I.; Yoo, H. K.; Mlynarek, J. *Polym Test* 2003, 22, 779.
11. Li, M.; Hsuan, Y. G. *Geotext Geomembr* 2004, 22, 511.
12. Bouazza, A. *Geotext Geomembr* 2004, 22, 531.
13. Wang, C. S. *Structural Modification on the Vegetation Planting Block*, TW Pat. 00,231,399 (1994).
14. O'Connor, R. T.; Du Pre, E. F.; McCall, E. R. *Anal Chem* 1957, 29, 998.
15. Aboul-Fetouh, M. S.; Miles, L. W. C. *Text Res J* 1968, 38, 176.
16. De Boer, J. J. *Text Res J* 1980, 50, 648.
17. Bertoniere, N. R.; King, W. D.; Rowland, S. P. *Text Res J* 1981, 51, 242.
18. Bertoniere, N. R.; King, W. D.; Rowland, S. P. *Text Res J* 1983, 53, 624.
19. Rowland, S. P.; Bertoniere, N. R.; King, W. D. *Text Res J* 1984, 54, 318.
20. Silverstein, R. M.; Bassler, G. C.; Morrill, T. C. *Spectrometric Identification of Organic Compounds*, 3rd ed.; Wiley: New York, 1974; p 136.