

Swelling and Antibacterial Properties for the Superabsorbent Hydrogels Containing Silver Nanoparticles

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ABSTRACT: A series of antibacterial superabsorbents containing silver nanoparticles based on sodium acrylate (SA), 1-vinyl-2-pyrrolidone-silver ion complex (VP-Ag⁺) and *N, N'*-methylene-bisacrylamide (NMBA) were prepared by inverse suspension polymerization. The ascorbic acid (vitamin C) was used as reductant to reduce silver ion complex in the gels through *in situ* reduction method. The influence of the concentration of VP-Ag⁺ complex in the superabsorbents on the water absorbency, swelling behavior, and antibacterial effect of *Candida albicans* was investigated. Results showed that the water absorbency

for sodium acrylate and VP copolymeric gel (SV gel) in deionized water was 1016 g H₂O/g gel, but the water absorbency for SV-Ag series gel decreased when the silver nanoparticle was added. Results also showed that the antibacterial effect of the superabsorbents increased with an increase of the silver concentration (1 ~ 10 ppm). © 2007 Wiley Periodicals, Inc. *J Appl Polym Sci* 106: 1992–1999, 2007

Key words: superabsorbents; silver nanoparticles; *Candida albicans*

INTRODUCTION

Superabsorbent is a three dimensional polymer and it contains an amount of strong hydrophilic groups such as —OH and —COO[−] groups. Superabsorbents have superior water absorbency compared with general water-absorbing materials such as sponge and cotton in which the absorbed water was hardly removable even under high temperature and pressure. The first superabsorbent was reported by the U.S. Department of Agriculture in 1961.¹ Then, much attention was paid to their applications. In recent years, the application of superabsorbent was widely used in medical materials and personal hygiene products due to their high absorbency and holding the water.^{2,3} The superabsorbent polymeric materials were reported in our previous reports.^{4–10} The monomer used was acrylic acid (AA) with degree of neutralization around 90%.

The selection of the antibacterial material is important on the medical materials or hygienic appliances. Silver nanoparticle is well known that it is an excellent antibacterial material. The preparation of silver nanoparticles was difficult because they were easily

agglomerate. In recent years, Zhang et al. used poly(1-vinyl-2-pyrrolidone) as the protected agent for the preparation of silver nanoparticles.^{11–15} Silver nanoparticles were usually prepared by chemical reduction method and ultraviolet irradiation method.¹⁶ In the chemical reduction method, the reductant such as formaldehyde was highly deleterious for human body. Sondi et al. reported that they used vitamin C (ascorbic acid) as the chemical reductant in the silver nanoparticles preparation.¹⁷

Polymer–metal nanocomposites can be obtained by two different approaches, namely, *ex-situ* and *in situ* techniques. In the *ex-situ* approach, nanoparticles were first produced by soft-chemistry routes and then dispersed into polymeric matrices. In the *in situ* methods, metal particles are generated inside a polymer matrix by decomposition or chemical reduction of a metallic precursor dissolved into the polymer.¹⁸ For example, silver ions are successfully reduced and dispersed in poly(vinyl pyrrolidone) (PVP), poly(vinyl alcohol), and poly(2-hydroxyethyl methacrylate) matrices. Another method was used to prepare polymer–silver nanoparticle composites with γ -irradiation, in which Ag⁺ reduction and the polymerization of monomer took place simultaneously.^{19,20} Zhang et al. further improved the simultaneous polymerization–reduction method to prepare PAN/silver nanoparticle composite.²¹

The nanocomposite hydrogels prepared from VP-Ag⁺ monomer complex were not found in the literatures. In our laboratory, a series of composite

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hydrogels containing silver nanoparticle used for bioadhesive, which were prepared from AA, poly (ethylene glycol) methyl ether acrylate (PEGMEA), and VP-Ag⁺ complex through the *in situ* polymerization, were reported in our previous studies.²²

In this study, a series of superabsorbents with antibacterial effect were prepared from sodium acrylate, VP-Ag⁺ complex, and NMBA by inverse suspension polymerization. The silver ions in complex gel were reduced by the chemical reduction of vitamin C. The effect of the concentration of the VP-Ag⁺ complex in the superabsorbent on the water absorbency, swelling behavior, and antibacterial effect for *Candida albicans* was investigated.

EXPERIMENTAL

Materials

1-vinyl-2-pyrrolidone (VP) as chelating agent was purchased from Aldrich Co (St. Louis, MO). Silver nitrate and sodium hydroxide were purchased from Nihon Shiyaku Industries (Osaka, Japan). AA was purified by vacuum distillation at 63°C/25 mmHg (Fluka Chemical Buchs, Switzerland). Sorbitan monostearate (Span 60) as a stabilizer was purchased from Tokyo Kasei Industries (Tokyo Japan). Ammonium persulfate (APS) as an initiator was purchased from Wako Pure Chemical Co. LTD (Osaka, Japan). *N, N'*-methylene-bisacrylamide (NMBA) as a cross-linker and vitamin C were obtained from Sigma Chemical Co (St. Louis, MO). Cyclohexane and methanol were of analytical grade reagent. Luria bertani (LB) medium and agar powder were purchased from Difco (Franklin Lakes, NJ). Phosphate buffered saline (PBS) was prepared by ATCC-phosphate buffered saline formulation Catalog No. SCRR-2201. *Aspergillus niger* (BCRC 30,130) and *Can-*

didia albicans (BCRC 20,511) were purchased from the Food Industry Research and Development Institute (Taipei, Taiwan).

Composition of SV series xerogels

The feed compositions of samples are listed in Table I. The compositions of the gels only changed the silver concentration. Degree of neutralization of AA is 90%, which has highest water absorbency in poly (SA) gel systems.⁶ This molar proportion of SA and VP has high yield. Because 1 mol of vitamin C can reduce 2 mol of silver ions,¹⁷ the double amount of vitamin C was used to enhance the reductive effect of silver ions inside the gels. The structures of VP-Ag⁺ complex and poly (SV-Ag⁺) gel are given as Schemes 1 and 2.

Preparation of superabsorbent polymeric gels

Preparation of complex solution

The complex solution was prepared from silver nitrate solid and pure VP monomer. The complex compositions are listed in Table I. The solution was stirred at 25°C until the color of complex solution became vermilion at 3 h.

Preparation of SA monomer solution

SA monomer solution was prepared from AA and sodium hydroxide solution as reported previously.⁶ The degree of neutralization was controlled at 90%.

Preparation of SV-Ag⁺ and SV gels

A 500 mL four-neck separable flask equipped with an agitator, a reflux condenser, inlet of nitrogen gas,

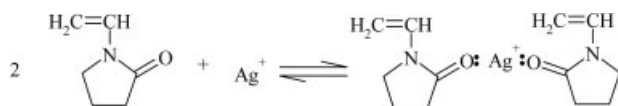
TABLE I
Characterization of SA/VP-Ag Complex Copolymeric Gels

Sample code	SV	SV-Ag1	SV-Ag2.5	SV-Ag5	SV-Ag10
Degree of neutralization (%)	90	90	90	90	90
SA (mole %)	90	90	90	90	90
VP (mole %)	10	10	10	10	10
AgNO ₃ (mole %)	0	0.1	0.25	0.5	1
VC (mole %)	0	0.1	0.25	0.5	1
NMBA (g)	0.07	0.07	0.07	0.07	0.07
APS (g)	0.15	0.15	0.15	0.15	0.15
Yield (%)	98.87	95.73	93.73	92.57	97.60
Water solubles (%)	5.96	6.06	8.74	6.87	7.53
Ag (wt %) ^a	0	0.13	0.25	0.56	1.12
Ag (ppm) ^b	0	1.3	2.5	5.6	11.2
Conversion of Ag (%)	0	88.20	83.31	86.15	92.70

The total mole is 0.213 mole.

^a Based on the total monomer weight.

^b Effect of *Candida albicans* inactivation for Antibiotic experiment.



Scheme 1 Reaction for VP-Ag⁺ complex solution.

and a thermometer was charged with 65 mL of cyclohexane and 0.15 g of Span 60. The mixture was stirred until Span 60 was dissolved (continuous phase).

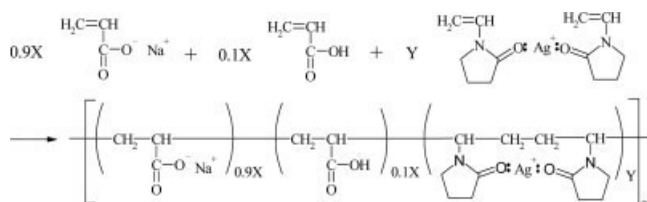
The dispersion phase solution contains sodium acrylate (SA) monomer, VP-Ag⁺ complex, and NMBA solution (the SV gel does not contain silver ion). The monomer solution (dispersion phase) and initiator, APS, were introduced into the reactor. Air was flushed from the reactor by introducing nitrogen until the entire process was completed. The polymerization was set at 70°C for 3 h and the stirrer speed was maintained at 400 rpm. After polymerization, the suspension solution was cooled and then precipitated by 250 mL methanol under stirring. The product was filtered and washed several times by the mixture of water and methanol (1 : 9 in volume ratio). Finally, the product was frozen to -20°C and then freeze-dried for three days. The color of all SV-Ag⁺ gels was aquamarine and SV gel was white. The yields of the SV series gels are above 92% and water solubles lie in between 5.96% and 8.74%.

Chemical reduction of SV-Ag⁺ gels

The silver nanoparticles in hydrogels were prepared from using vitamin C as reductant by chemical reduction method. The volume ratio of methanol to vitamin C solution was 2 : 3. All samples were immersed in the solution for 1 day at room temperature. Finally, all samples were frozen to -20°C and then freeze-dried for three days. The colors of SV-Ag1, SV-Ag2.5, SV-Ag5, and SV-Ag10 gel were khaki, green, brown, and bister, respectively.

Measurement of water absorbency

All samples with particle size in the range between 65 and 100 mesh were frozen to -20°C and then freeze-dried for 1 day before any tests.



Scheme 2 Polymerization for poly (SV-Ag⁺) gel.

Tea bag method^{5-7,11}

The tea bag was made of 250 mesh nylon screen. The tea bag containing the dried sample (50 mg) was immersed in an excess of deionized water for 1 day to reach the swelling equilibrium at room temperature, and then hung up for 30 min to drain the excess solution and weighed. The absorbency (Q) was calculated by eq. (1):

$$Q = \frac{W_{tb} - W_b - W_d}{W_d} \quad (1)$$

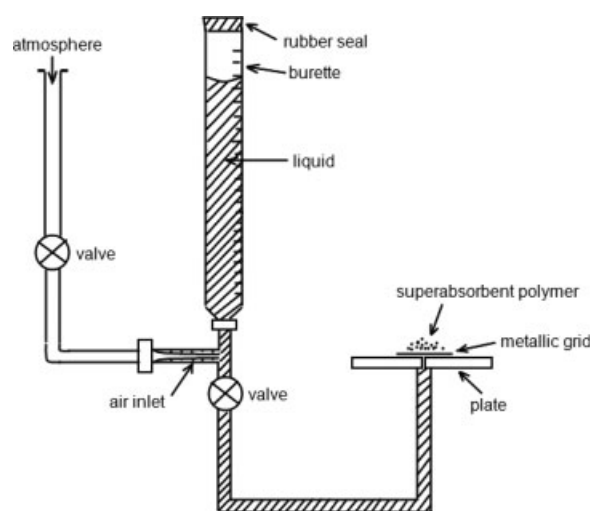
where Q is the absorbency of the xerogel, W_{tb} is the weight of the tea bag and swollen sample, W_b is the weight of the tea bag, and W_d is the weight of the dried sample.

Kinetics of swelling

A technique based on the demand wettability (DW) method was adopted as shown in Scheme 3.^{23,24} A graduated burette with an air inlet at the bottom was linked by a flexible tube to a plate covered with a metallic grid (300 mesh). After filling with deionized water, the burette was closed at the top and air was introduced while the xerogels absorbed water. The sample (10 mg) of absorbent was placed on the grid, and the swelling kinetics was easily measured. The absorbency at every time interval was calculated by eq. (2):

$$Q_d = \frac{V_s \times d_{H_2O}}{W_d} \quad (2)$$

where Q_d is the characteristic absorbency of water, V_s is absorbed volume, d_{H_2O} is the density of water, and W_d is the weight of the dried sample.



Scheme 3 Schematic equipment for demand wettability method.

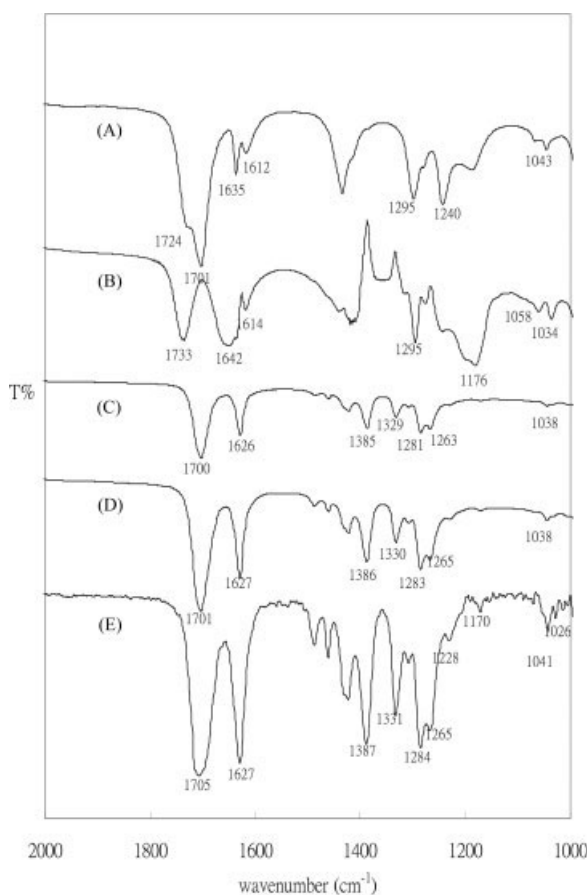


Figure 1 FT-IR spectrum of (A) Pure AA, (B) VP-Ag⁺+AA, (C) VP-Ag⁺2.5, (D) VP-Ag⁺1, and (E) Pure VP.

Measurement of the conversion of silver in the gels²²

The dried sample (10 mg) was immersed in 10 mL of 0.3N nitric acid solutions for 1 day at room temperature to dissolve silver particle inside the gel. The reaction is as eq. (3). The extracted solution was removed by suction filtration with an aspirator when the color of gel sample became limpid. Silver con-

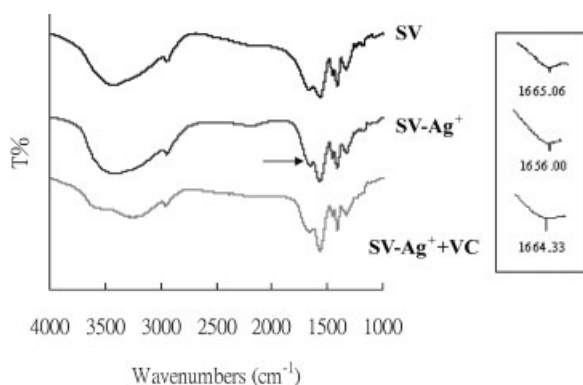
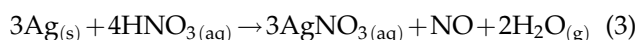


Figure 2 FT-IR spectra of SV gel, SV-Ag⁺ gel, and vitamin C solution added to SV-Ag⁺ gel.

centration was monitored from the extracted solution by atomic absorption spectrometer (AAS, Varian Spectra AA 220). The conversions of the silver ion in the SV-Ag series gels are ranged from 83.3 to 92.7% (see Table I).



Antibacterial experiment

Qualitative analysis

Aspergillus niger was used for qualitative analysis in the antibacterial effect. The antibacterial effect was not obvious for the SV series gels because silver concentration was trace (0 ~ 10 ppm). Therefore, the SA gels (not contain VP) were used in the experiment and composition was 100 mol % of SA. The dried gel was immersed in AgNO₃ solutions (100 and 1000 ppm) for 1 day to load silver ion into the gel and subsequently immersed into vitamin C solution for 1 day to reduce the silver ion to silver particle. The freeze-dried process was used to dry the gels.

PDA (Potato dextrose agar) was used as the standard culture of *aspergillus niger*. About 30 mL of sterile water (NaCl solution, 0.85%) was added into each of four test tubes (blank, SA, SA-100ppm Ag and SA-1000 ppm Ag) and then 50 mg of dried gel sample was immersed in the test tube for 1 day to swell. A little of *aspergillus niger* taken from PDA culture was put into each test tube, the mycelium was dispersed by shaker. Finally, microbial solutions were static at 30°C for 1 day. The acervation of *aspergillus niger* on the gel was observed by electron microscope.

Quantitative analysis

Candida albicans was used for quantitative analysis in the antibacterial effect. LB was used as the culture of *Candida albicans* for the Petri dish experiment. A little of *Candida albicans* taken from LB and agar culture (15 mL, 25°C, 4 days) was placed in 100 mL LB solu-

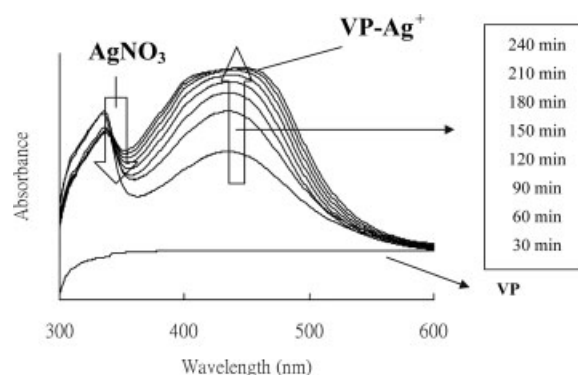


Figure 3 UV absorbance for pure VP monomer and VP-Ag⁺ complex solution during VP and Ag⁺ formation process.

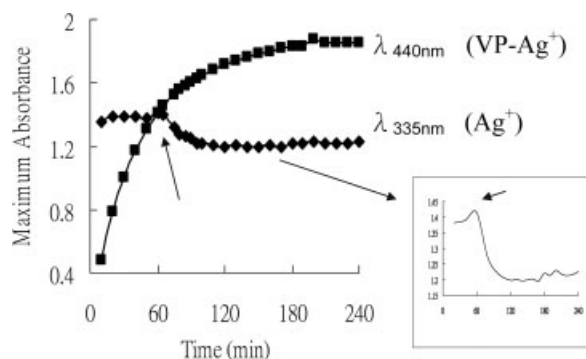


Figure 4 The maximum UV absorbance at $\lambda_{440\text{ nm}}$ and $\lambda_{335\text{ nm}}$ for VP-Ag⁺ and Ag⁺ during complex formation process.

tion and inoculated at 37°C with 180 rpm shaking rate for 1 day. The solution with *Candida albicans* (1 mL) was separated by the abbreviated centrifuge for 3 min. All of *Candida albicans* sediment was immersed in 1 mL of PBS solution. 0.1 mL of PBS sediment was diluted to 100 mL of PBS.

Six Erlenmeyer flasks (blank, SV, SV-Ag1, SV-Ag2.5, SV-Ag5, and SV-Ag10) containing 100 mL of the sterile water and the gels (100 mg) were static for 1 day at room temperature. They were autoclaved at 121°C and 15 min for sterilization. One milliliter of PBS sediment was added to each Erlenmeyer flask. A total of 0.5 mL of the solution taken from the Erlenmeyer flask was diluted with sterile water to 10⁴ times on the time of 0, 30, 60, 90, and 120 min. About 0.1 mL of the diluted solution was dropped to the Petri dish (15 mL, LB and agar) for 2 days at room temperature. Finally, the colonies were calculated from the Petri dish. The inactivation efficiency was defined by eq. (4):

$$\text{Inactivation efficiency (\%)} = \frac{S - A}{S} \times 100\% \quad (4)$$

where S is the number of colony for SV gel and A is the number of colony for SV-Ag gels.

RESULTS AND DISCUSSION

Characterization of VP-Ag⁺ complex

The VP-Ag⁺ complex analysis was performed by FT/IR (Horiba, Spectrum GX) and UV/visible spec-

trometer (Jasco V-530). Wang et al. showed that the chelate bonding of silver ion with poly(vinyl pyrrolidone) (PVP) was both occurred at C—N and C=O groups.^{12,13} But, in our system, the absorption peak of C—N group in VP monomer with silver ion was too weak from FT-IR spectrum, so the [C—N···Ag⁺] bonding for the complex structure was uncertain. Hence, we only demonstrated the [C=O···Ag⁺] bonding change of the various complex compositions.

FT-IR analysis

The FT-IR spectra for the VP and various VP-Ag⁺ complex compositions were shown in Figure 1. The characteristic absorption peaks of C=O bond and C—N bond for VP monomer were 1705 cm⁻¹ and 1170 cm⁻¹, respectively, [Fig. 1(E)], but the absorption peak of C=O bond was shifted to 1700 cm⁻¹ after 3 h of the VP/AgNO₃ complex reaction. This phenomenon suggests that the oxygen atom in carbonyl of VP monomer was chelated with the silver ion. When silver ion was closed to the oxygen atom of VP monomer by electronic attraction, oxygen atom can allow electron for empty valance orbital of silver ion, they were became the coordination compound. The blue shift was generated when the electron-cloud density of bond decreased. In addition, the absorption peak of C—N bond in VP monomer with silver ion almost disappeared after 3 h of the VP/AgNO₃ complex reaction [Fig. 1(C,D)]. Hence, its absorption strength was too weak.

The FT-IR spectra of the SV gel, SV-Ag⁺ gel, and SV-Ag⁺ gel containing vitamin C were shown in Figure 2. The characteristic absorption peak of the C=O stretching for the SV gel was appeared at 1665 cm⁻¹, but that was shifted to 1656 cm⁻¹ for the SV-Ag⁺ gel. This blue shift phenomenon was the same as the VP-Ag⁺ complex as shown in Figure 1. But, the characteristic absorption peak of the C=O stretching returned to the original 1664 cm⁻¹ when the silver ion was reduced to the silver nanoparticle by vitamin C.

UV/visible analysis

The traces of complex formation for VP and AgNO₃ solid (VP : AgNO₃ = 1 : 0.025) were monitored by UV absorbance. The results are shown in Figure 3.

TABLE II
Water Absorbency for SV and SV-Ag gels in Deionized Water

	SV	SV-Ag1	SV-Ag2.5	SV-Ag5	SV-Ag10
Tea-bag method (g H ₂ O/g gel)	1016 ± 20	741 ± 36	729 ± 23	719 ± 28	733 ± 11

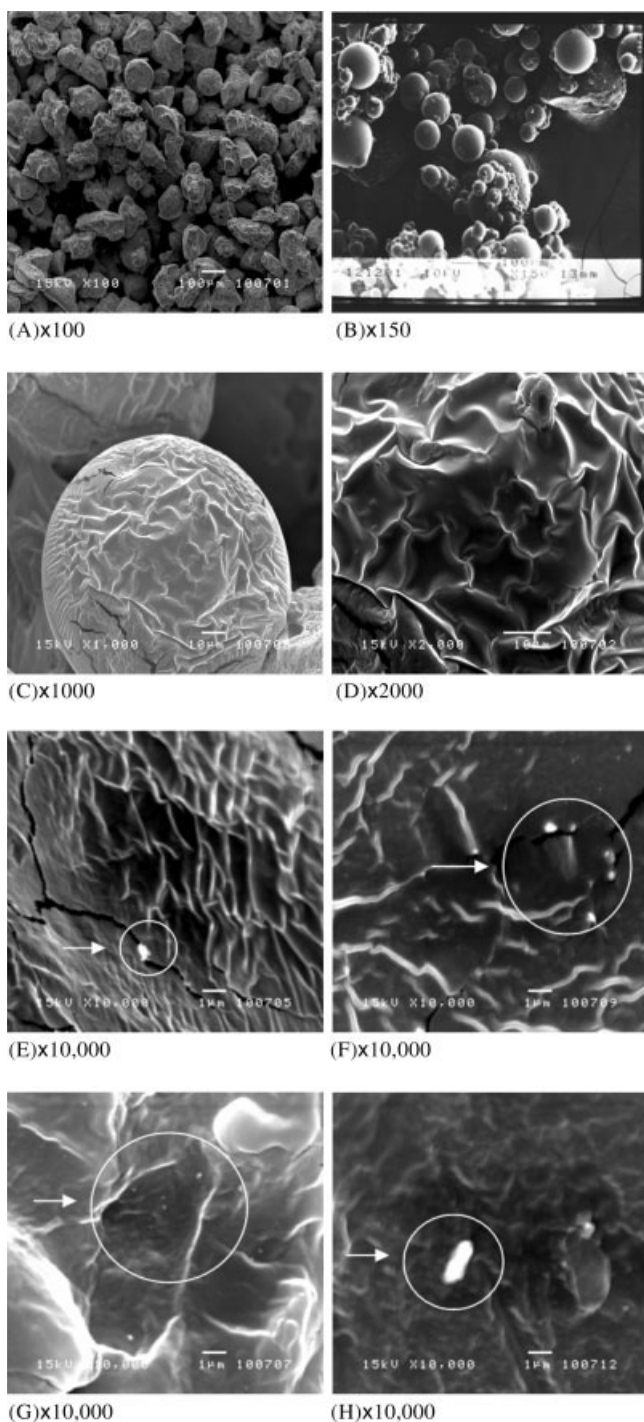


Figure 5 Scanning electron micrograph for xerogels. (A) ~ (D) SV, (E) SV-Ag1, (F) SV-Ag2.5, (G) SV-Ag5 and (H) SV-Ag10.

The first peak appeared at 335 nm is the silver ion absorption, the second peak appeared at 440 nm is the VP-Ag⁺ complex absorption. The first peak appeared when the AgNO₃ was added into VP liquid at the initial time, it was only one peak at this situation. The absorbance of silver ion decreased when the complex formation was occurred, but the

absorbance of VP-Ag⁺ complex increased with the reaction time.

The maximum absorbance for Ag⁺ and VP-Ag⁺, respectively, appeared at λ_{335} nm and λ_{440} nm is shown in Figure 4. The results in Figure 4 indicate that the maximum absorbance of silver ion at λ_{335} nm increases until 1 h due to the AgNO₃ solid gradually dissolved in the VP liquid. After 1 h, the AgNO₃ solid was dissolved completely, and then the maximum absorbance rapidly decreases until 2 h and then approaches to constant absorbance. After 3 h, the maximum absorbance slightly increases. This behavior suggests that the reaction of complex formation is reversible. The result shown in Figure 4 also indicates that the maximum absorbance of VP-Ag⁺ at λ_{440} nm increases with the reaction time until 3 h and then approaches to constant absorbance.

Effect of silver content on water absorbency in deionized water

The water absorbency in deionized water measured by tea bag method as a function of the content of silver particle in the copolymeric gels is shown in Table II. The results show that the water absorbencies for the SV-Ag series gels with silver nanoparticles are lower than those for the gel without silver nanoparticle (SV). This result suggests that the carboxylate or carboxylic acid groups of the AA would complex with silver ion when the VP-Ag⁺ was added into the acrylate solution to perform inverse suspension polymerization. That occurrence could reduce the ionic repulsion of the copolymeric gels and decrease the water absorbency of the copolymeric gels. To verify this complexation, the complex of VP-Ag⁺ was added into AA with same composition as their polymerization condition and then detected their IR spectra. The results are also shown in Figure 1 and indicate that when the equal molar of VP-Ag⁺ and AA was thoroughly mixed, the peak of 1176 cm⁻¹ reappeared and the peak of 1700 cm⁻¹ red shifted to 1733 cm⁻¹ [see Fig. 1(A,B)]. This result can be implied that the silver ion in VP-Ag⁺ complex would transfer to COO⁻ group in acrylate in polymerization process.

Table II shows that the water absorbency for SV gel in deionized water is 1016g H₂O/g gel, but those for SV-Ag series gels range from 719 to 741 g H₂O/g gel. This result also indicates that the water absorbencies for the gels are not apparently affected by silver nanoparticle content when a small amount of silver nanoparticles was added into the gels (0.1 ~ 1 wt %).

SEM analysis

The microphotographs of the silver particles in SV and SV-Ag series nanocomposite superabsorbents

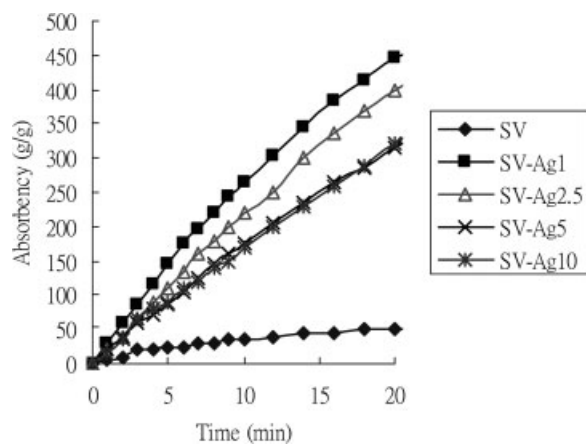


Figure 6 Absorption rate in deionized water for SV and SV-Ag xerogels by DW method.

observed from SEM are shown in Figure 5. Figure 5(A,B) show the image of the pulverized SV gel. As shown in these figures, the particles obtained from inverse suspension polymerization approach to spherical shape and some aggregates occur. Figure 5(C,D) shows the spherical particle of the gel with a magnification of 1000 and 2000, respectively. The corrugation of particle surface was observed due to freezing dry. The silver particles marked with white circles for SV-Ag series gels are observed from Figure 5(E,H) with a magnification of 10,000. The silver particle distribution increases with increase in the silver concentration. Figure 5(G) shows the lowest silver particle size for the SV-Ag5 gel, but Figure 5(H) shows the silver particle susceptible to agglomerate when the silver concentration is 1.12 wt %.

Effect of silver nanoparticle content on initial absorption rate for the copolymeric gels

Buchholz²⁵ has suggested that the swelling kinetic for the absorbent is significantly influenced by swelling capacity, size distribution of powder particles, specific surface area, and apparent density of the polymer.

Figure 6 shows the absorption rate in deionized water for SV and SV-Ag series copolymeric gels. The results shown in Figure 6 indicate that the tendency of the initial absorption rate is in the order SV-Ag1 > SV-Ag 2.5 > SV-Ag5 = SV-Ag10 ≫ SV. This result indicates that the higher density of silver nanoparticle in the gel would hamper the water to diffuse into the gel and decrease the initial absorption rate. In addition, the initial absorption rate for the SV gel is lower than those for SV-Ag series gels. This result is contrary to the tendency of water absorbency for the present series gels and contrary to our previous

report in preparation and properties of nanocomposite hydrogels containing silver nanoparticles by *ex-situ* polymerization.²²

Effect of silver nanoparticle content on bacterial inactivation for the superabsorbent gels

Qualitative analysis

The effect of the content of silver particle on bacteria inactivation was performed in the present superabsorbents. The *aspergillus niger* was used in this experiment. The growth of the *aspergillus niger* in the culture medium with the gels containing silver particle was observed by electron microscopy. Much mycelium of *aspergillus niger* were observed from Figure 7(A) in the blank. When the culture medium added SA gel without any silver particle, the mycelium of *aspergillus niger* was still full of the culture medium and covered the surface of the gels [see Fig. 7(B)]. When the culture medium added SA gel with lower content of silver particle (100 ppm), the mycelium of *aspergillus niger* on the surface of the gels slightly decreases and can be observed from Figure 7(C). But, when the culture medium added SA gel with higher content of silver particle (1000 ppm), the mycelium of *aspergillus niger* on the surface of the gels observed from Figure 7(D) significantly decreases. The silver nanoparticles, black dots, on the inside of the gel were agglomerate. The above results explicitly indicate that the effect of silver particle content in the gel on *aspergillus niger* inactivation is available.

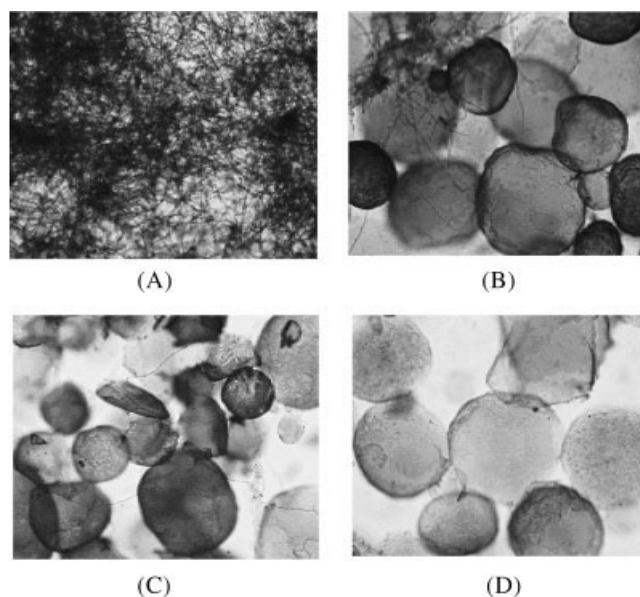


Figure 7 *Aspergillus niger* inactivation by SA gels: (A) *Aspergillus niger*, (B) 0 ppm Ag, (C) lower silver concentration (100 ppm), (D) higher silver concentration (1000 ppm).

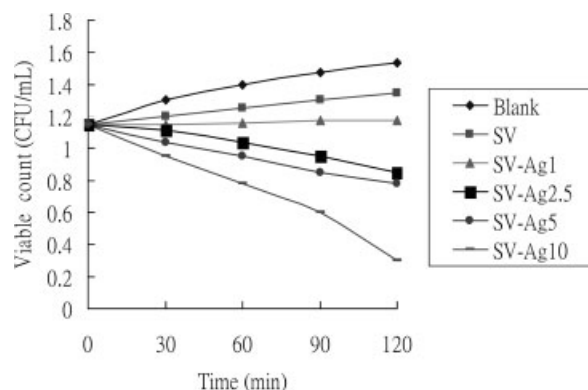


Figure 8 Inactivation of *Candida albicans* by SV series gels.

Quantification analysis

It is well known that silver nanoparticles have a bacterial inactivation effect and inflammation action. The inactivation of *Candida albicans* for the SV series gels as a function of time is shown in Figure 8. The results shown in Figure 8 indicate that the tendency of the *Candida albicans* inactivation for the SV series gels is in the order SV-Ag10 > SV-Ag5 > SV-Ag2.5 > SV-Ag1.0 > SV. That is, the bacterial inactivation of the SV series gels increases with increase in the silver content in the nanocomposite gel.

The inactivation efficiencies of *Candida albicans* for the SV series gels as a function of time are shown in Figure 9. The result shows that the gel even with lower of silver concentration (SV-Ag1, 1 ppm Ag) has antibacterial effect. And, the inactivation efficiencies increase with increase in the silver content and achieve 90% for SV-Ag10 (10 ppm Ag) gel at 2 h.

CONCLUSIONS

A series of antibacterial superabsorbents containing silver nanoparticles based on sodium acrylate (SA), 1-vinyl-2-pyrrolidone-silver ion complex (VP-Ag⁺)

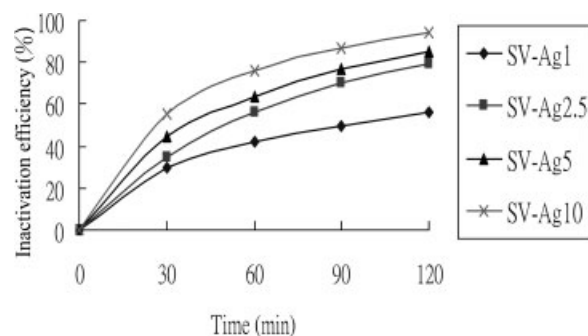


Figure 9 Time courses of *Candida albicans* inactivation efficiency by xerogels with various concentrations of silver nanoparticles.

and *N,N'*-methylene-bisacrylamide (NMBA) were successfully prepared by inverse suspension polymerization. The structures of (VP-Ag⁺) were confirmed by IR and UV techniques. The water absorbencies for the SV-Ag series gels with silver nanoparticles are lower than those for the gel without silver nanoparticle (SV), but the water absorbencies for the gels are not apparently affected by silver nanoparticle content when a small amount of silver nanoparticles was added into the gels (0.1 ~ 1 wt %). The *Candida albicans* inactivation for the SV series gels increases with increase in the silver content in the nanocomposite gel and the inactivation efficiencies increase with increase in the silver content and achieve 90% for SV-Ag10 gel at 2 h.

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