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Rapid microwave-assisted preparation and characterization of cellulose–silver nanocomposites

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ABSTRACT

A simple, rapid, and efficient microwave-assisted synthesis of cellulose–silver nanocomposites with silver nanoparticles homogeneously dispersed in the cellulose matrix using cellulose solution, $AgNO_3$ and ascorbic acid in *N*,*N*-dimethylacetamide (DMAc) is reported. The cellulose solution was prepared by the dissolution of microcrystalline cellulose in a solvent system of lithium chloride (LiCl)/DMAc. The effects of the microwave heating times and ascorbic acid concentration on the nanocomposites were investigated. The microstructure, size, morphology, and thermal properties of these nanocomposites were analyzed with X-ray diffraction (XRD), Fourier transform infrared (FT-IR), thermogravimetric analysis (TG), differential scanning calorimetric analysis (DSC), and scanning electron microscopy (SEM). The results revealed that the ascorbic acid concentration played an important role in the phase of the nanocomposites. This work provided a promising way to prepare cellulose–silver nanocomposites with good dispersity.

1. Introduction

Cellulose is the most abundant biomass and renewable resource on earth, is biodegradable, biocompatible and non-toxic, and can be converted into cellulose derivatives and regenerated materials (Klemm, Heublein, Fink, & Bohn, 2005). Nanocomposites are one of the most promising materials with broad applications (Corr, Rakovich, & Gunko, 2008; Hatton, Landskron, Whitnall, Perovic, & Ozin, 2005; Huang, Zhang, Kotaki, & Ramakrishna, 2003; Sanchez, Julian, Belleville, & Popall, 2005). More recently, cellulose-based nanocomposites and their derivatives have attracted great attention and showed more and more importance over the last two decades due to their high value-added applications in science and technology (Deng, Zhou, Du, Van Kasteren, & Wang, 2009; Liu, Zhang, Zhou, & Wu, 2008; Murakami, Kaneko, & Kadokawa, 2007; Ruan, Huang, & Zhang, 2005; Tsioptsias & Panayiotou, 2008). Gindl and Keckes (2005) presented cellulose-based nanocomposite films with different ratios of cellulose I and II, which were produced by means of partial dissolution of microcrystalline cellulose powder and subsequent film casting. Wu, Henriksson, Liu, and Berglund (2007) successfully synthesized a high-strength elastomeric nanocomposite by dispersing microcrystalline cellulose in a polyurethane matrix.

It is well known that silver is superior to other metals in many fields and has various applications in antimicrobial effects (Feng, Cui, & Kim, 1999), electrical conductivity (Chang & Yen, 1995), optical properties (Fritzsche, Porwol, Wiegand, Bornmann, & Kohler, 1998), and oxidative catalysis (Shiraishi & Toshima, 2000). Varieties of silver with different morphologies including nanowires (Zhu & Hu, 2004), nanorods (Liu, Huang, Chu, & Ko, 2005), nanopowders (Chau, Hsu, Hsieh, & Kao, 2005), and nanoparticles (Gao, Lu, & Komarneni, 2005; Zhu & Zhu, 2006) have been reported. There have been a large number of reports on the fabrication of silver-based nanocomposites (Cascaval et al., 2007; Choi, Lee, & Park, 2003; Leopold & Lendl, 2003; Manna, Batabyal, & Nandi, 2006; Schaaff & Rodinone, 2003). However, there have been only few reports on the fabrication of bacterial cellulose–silver nanocomposites (Maneerung, Tokura, & Rujiravanit, 2008; Maria et al., 2009; Marques, Nogueira, Pinto, Neto, & Trindade, 2008; Zhu, Xue, & He, 2009). For example, Maneerung et al. (2008) synthesized bacterial cellulose–silver nanocomposites with strong antimicrobial activity against *Escherichia coli* (Gram-negative) and *Staphylococcus aureus* (Gram-positive) using sodium borohydride as reducing agents by immersing bacterial cellulose in silver nitrate solution. Marques et al. (2008) reported the synthesis of bacterial cellulose–silver nanocomposites and their performance as surface enhanced Raman scattering substrates. Maria et al. (2009) synthesized bacterial cellulose/colloidal silver nanocomposites using different reductants (hydrazine, hydroxylamine or ascorbic acid) together with gelatin or polyvinylpyrrolidone. Zhu et al. (2009) presented in situ synthesis of silver nanoparticles in natural cellulose fibers using sodium

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borohydride as reductants. Chen, Wang, Zhang, and Jin (2008) reported the synthesis of silver nanoparticles using sodium carboxymethylcellulose (CMC) as a stabilizing reagent by microwave heating method.

Microwave irradiation as a high efficient heating method has widely applications in chemosynthesis (Polshettiwar & Varma, 2008; Sauer, Kalvin, & Phelan, 2003; Zhu et al., 2006). Currently, microwave heating provides a promising method for the preparation of metallic nanoparticles (Liao, Zhu, Zhu, Xu, & Chen, 2001; Palchik, Zhu, & Gedanken, 2000; Tsuji, Hashimoto, Nishizawa, Kubokawa, & Tsuji, 2005; Xu, Yang, Liu, & Lin, 2000) due to its characteristics of rapid volumetric heating, high reaction rate, short reaction time, enhanced reaction selectivity, and energy saving (Liu et al., 2003). It is known that the effect of the microwave heating is created by the interaction of the dipole moment of molecules with the high-frequency electromagnetic radiation. The DMAc molecule has a large dipole moment. So it is one of the best solvents for microwave heating and used here as solvent for the synthesis of cellulose–silver nanocomposites.

Environmentally friendly microwave heating was usually applied to the dissolution of cellulose in solution so as to obtain cellulose derivatives and regenerated materials. Antova, Vasvasova, and Zlatanov (2004) studied the synthesis of cellulose stearate by transesterification of methylstearate with low-molecular microcrystalline cellulose under microwave heating. Sarotti, Spanevello, and Suarez (2007) reported the microwave-assisted pyrolysis of cellulose into levoglucosenone with high yield. Dogan and Hilmioglu (2009) reported the dissolution of cellulose with *N*-methylmorpholine-*N*-oxide by microwave heating. Possidonio, Fidale, and Seoud (2009) studied the microwave-assisted cellulose dissolution in ionic liquids without changing degree of polymerization of microcrystalline cellulose.

Herein, we introduced a rapid and facile method to prepare cellulose–silver nanocomposites by microwave heating using $AgNO_3$, *N*,*N*-dimethylacetamide (DMAc), ascorbic acid, and cellulose solution. This method is based on the one-step simultaneous formation of Ag nanoparticles and precipitation of the cellulose, leading to a homogeneous distribution of Ag nanoparticles in cellulose matrix. The microwave-assisted method is favorable for the crystallinity of Ag and the precipitation of cellulose. It is well known that ascorbic acid is widely used in preparation of metal nanostructures as reducing agent (Miranda, Dollahon, & Ahmadi, 2006; Biçer & Şişman, 2010). The syntheses of silver nanostructures using ascorbic acid as reducing agent have been reported (Sondi, Goia, & Matijević, 2003; Wu & Meng, 2005). Ascorbic acid was chosen as reducing agent due to its mild reduction ability.

2. Experimental

2.1. Materials

All chemical materials and solvents used in the experiments were analytical grade reagents, and were used without further purification. Microcrystalline cellulose (molecular weight of 34,843–38,894, with a degree of polymerization of 215–240) was obtained from Sinopharm Group Chemical Reagent Co., Ltd., Shanghai, China. *N*,*N*-dimethylacetamide (DMAc), lithium chloride (LiCl), ascorbic acid, and silver nitrate were purchased from Beijing Chemical Works.

2.2. Synthetic process of the cellulose–silver nanocomposites

A typical synthesis experiment for the cellulose solution was carried out as follows: 3.044 g of LiCl was added into 40 mL of DMAc under vigorous stirring to form LiCl/DMAc solution. After that, 2.848 g of microcrystalline cellulose was dissolved directly into the aqueous LiCl/DMAc solution under vigorous stirring to prepare the cellulose solution. The solvent was then heated by an oil bath at 90 °C for 3 h.

To obtain cellulose–silver nanocomposites, the obtained cellulose solution (5 mL) was added directly into DMAc (30 mL), and then 0.338 g of $AgNO_3$ and 3.000 g of ascorbic acid were added into the resulting colloidal solution under vigorous stirring. The solution was heated to a certain temperature and kept at this temperature for a certain time by microwave heating, and then air cooled to room temperature naturally. The microwave oven used for sample preparation was purchased from Beijing Xiang-Hu Science and Technology Development Reagent Co., Ltd., which was equipped with the magnetic stirring system and a water-cooled condenser outside the microwave cavity. The product was obtained by centrifugation from the solution, three-time ethanol washed and dried at 60 °C in vacuum.

2.3. Characterization

The morphology of cellulose–silver nanocomposites was examined using a Hitachi 3400 N scanning electron microscopy (SEM). FT-IR spectrophotometer (Nicolet 510) was used to identify the ingredients of the nanocomposites, using the KBr disk method. X-ray diffractometer (XRD) patterns were recorded in the range of $2\theta = 10–70°$ on an X'Pert PRO MPD diffractometer operating at 40 kV with Cu Kα ($\lambda = 1.5405$ Å) radiation. Thermogravimetric analysis (TG) and differential scanning calorimetric analysis (DSC) was performed on a STA-409PC/4/H Luxx simultaneous TG/DSC apparatus (Netzsch Co., Selb, Germany) at a heating rate of 10 °C/min from room temperature to 700 °C under air atmosphere. Solid-state ^{13}C cross-polarization magic angle spinning (CP/MAS) NMR spectrum were obtained on a Bruker AVIII 400 MHz spectrometer.

3. Results and discussion

3.1. X-ray powder diffraction characterization

The phases of the products were investigated by XRD patterns. Fig. 1d shows XRD pattern of the typical sample synthesized by microwave-assisted method using cellulose solution, $AgNO_3$ and ascorbic acid in DMAc at 150 °C for 40 min. The sample has the

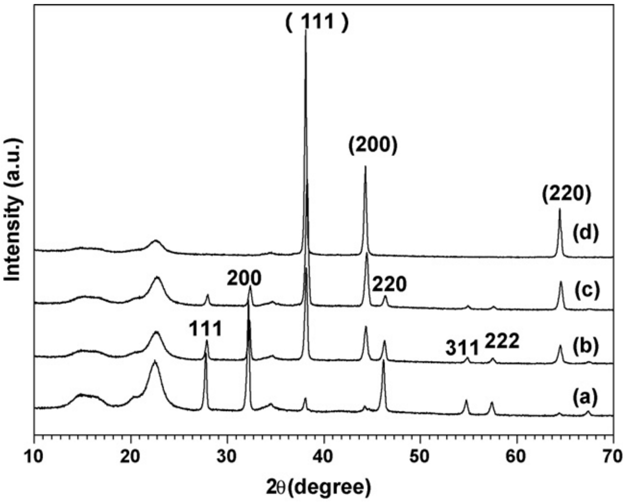


Fig. 1. XRD patterns of the cellulose-based nanocomposites prepared by microwave heating the DMAc solution of 0.338 g of $AgNO_3$, cellulose solution, and different ascorbic acid concentrations at 150 °C for 40 min. The amounts of ascorbic acid used were: (a) 0.352 g; (b) 1.000 g; (c) 2.000 g; and (d) 3.000 g.

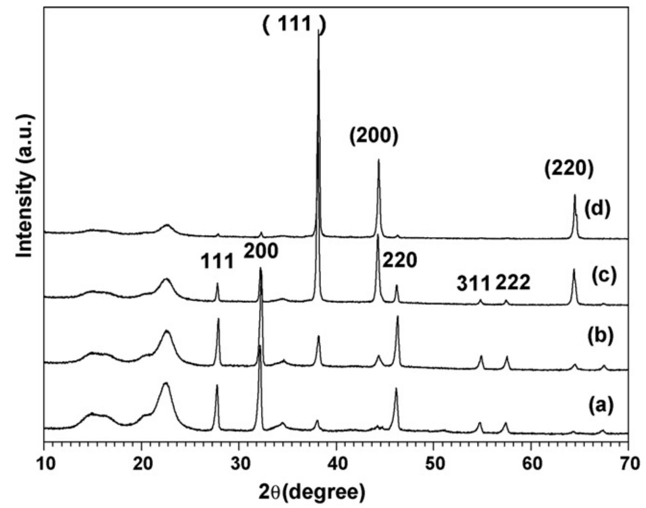


Fig. 2. XRD patterns of the cellulose-based nanocomposites prepared by oil bath the DMAc solution of 0.338 g of $AgNO_3$, cellulose solution, and different ascorbic acid concentrations at 150 °C for 40 min. The amounts of ascorbic acid used were: (a) 0.352 g; (b) 1.000 g; (c) 2.000 g; and (d) 3.000 g.

diffraction peaks at around *2θ* = 23° and 14.5–16.5°, corresponding to the typical diffraction pattern of cellulose (Fig. 1d). The other diffraction peaks were assigned to the (1 1 1), (2 0 0) and (2 2 0) planes of well-crystallized silver with a cubic structure (JCPDS 04-0783). No peaks from impurities were observed. The XRD result indicated that the cellulose–silver nanocomposites were successfully synthesized.

To investigate the effect of ascorbic acid on the nanocomposites, the samples were synthesized using different ascorbic acid concentrations at 150 °C for 40 min, while the other reaction conditions were the same. When the ascorbic acid amount was 0.352 g, the major phase of the nanocomposites consisted of cellulose and well-crystallized AgCl with a cubic structure (JCPDS 31-1238), and the nanocomposites also displayed tiny peaks at *2θ* = 38.0° and 44.3°, corresponding to the characteristic peaks of the crystalline plane (1 1 1) and (2 0 0) of silver (Fig. 1a). When the ascorbic acid amount was increased to 1.000 g, the major phase of nanocomposites consisted of cellulose and AgCl, the minor phase was silver (Fig. 1b). The peak intensity of cellulose and AgCl decreased and the peak intensity of silver increased, compared with Fig. 1a. When the ascorbic acid amount was further increased to 2.000 g, the major phases of nanocomposites were cellulose and silver, and the AgCl existed as a minor phase (Fig. 1c). When the ascorbic acid amount was increased to 3.000 g, the cellulose–silver nanocomposites were obtained (Fig. 1d). From Fig. 1, one can clearly see the process of phase transform from cellulose–AgCl to cellulose–silver nanocomposites. Moreover, the peak intensity of cellulose decreased and the peak intensity of silver increased with increasing ascorbic acid concentration. Therefore, the appropriate ascorbic acid concentration is important for the formation of cellulose–silver nanocomposites.

To investigate the effect of heating method on the phase of nanocomposites, the samples were also synthesized using oil bath at 150 °C for 40 min. The corresponding XRD patterns are shown in Fig. 2. When the ascorbic acid amount was increased to 1.000 g, the (2 2 0) peak of AgCl has still stronger intensity than the (2 0 0) peak of silver (Fig. 2b), compared with Fig. 1b, indicating that microwave-assisted method is favorable to the phase transformation of AgCl to silver. Moreover, even when the ascorbic acid amount was increased to 3.000 g, the (1 1 1), (2 0 0), and (2 2 0) peaks of AgCl still existed in the case of oil bath heating (Fig. 2d). On the contrary, the cellulose–silver nanocomposites were obtained by microwave-assisted heating (Fig. 1d). This result further confirms that the heating method had an influence on the phase of nanocomposites.

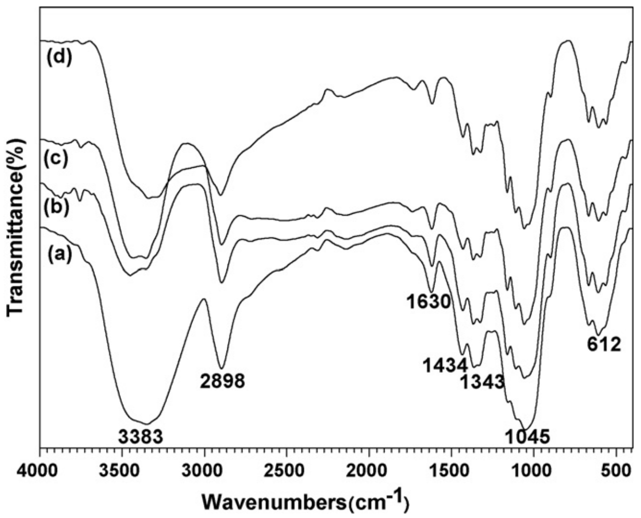


Fig. 3. FT-IR spectra of the cellulose-based nanocomposites as in Fig. 1.

3.2. FT-IR characterization

Fig. 3 shows FT-IR spectra of the nanocomposites using different ascorbic acid concentrations. The following characteristic absorptions in the FT-IR spectra were observed: bands at around 1045 cm^{-1} corresponded to C–O–C stretching mode from the glucosidic units; a characteristic band around 2898 cm^{-1} attributed to C–H groups; the large absorption band at 3300–3450 cm^{-1} assigned to the stretching vibrations of hydroxyl group and hydrogen bond (Suflet, Chitanu, & Popa, 2006). It is noted that the peaks at 1434 cm^{-1} corresponded to the symmetric bending of CH_2. As shown in Fig. 3 the FT-IR spectra of the nanocomposites are similar and consistent with the standard infrared spectrum of original microcrystalline cellulose (Uese, Pineda, & Hechenleitner, 2000). The peaks in the range of about 2130–2400 cm^{-1} were omitted due to it is sensitive to carbon dioxide in the atmosphere. From Fig. 3, we observed that the characteristic absorptions of cellulose appeared in the IR spectra of the nanocomposites.

3.3. TG/DSC analysis

TG/DSC results show the effects of temperature on the thermal behavior and interactions taking place in the cellulose–silver nanocomposites (Fig. 4). TG was undertaken in an air atmosphere to study the thermal stability of the materials produced. The TG curve of the cellulose–silver nanocomposites exhibits a small weight loss about 110 °C due to the loss of hydrated and coordinated water molecules, which come from the ambient environment. From TG curves, it is observed that the weight loss takes places at two stages, indicating the thermal degradation and complete decomposition of cellulose. The total mass losses of different samples were 94.5%, 89.2%, 42.7%, and 65.3% (Fig. 4A). The DSC curves for all the samples show two obvious broad exothermic peaks located around (331 and 480), (348 and 511), (330 and 456), and (340 and 431) °C (Fig. 4B), respectively, testifying that the TG profiles are in good agreement with the DSC results of these nanocomposites.

TG/DSC results of the nanocomposites synthesized by oil bath heating are also shown in Fig. 5. The total mass losses of different samples were 95.0%, 92.4%, 84.4%, and 76.2% (Fig. 5A). The total

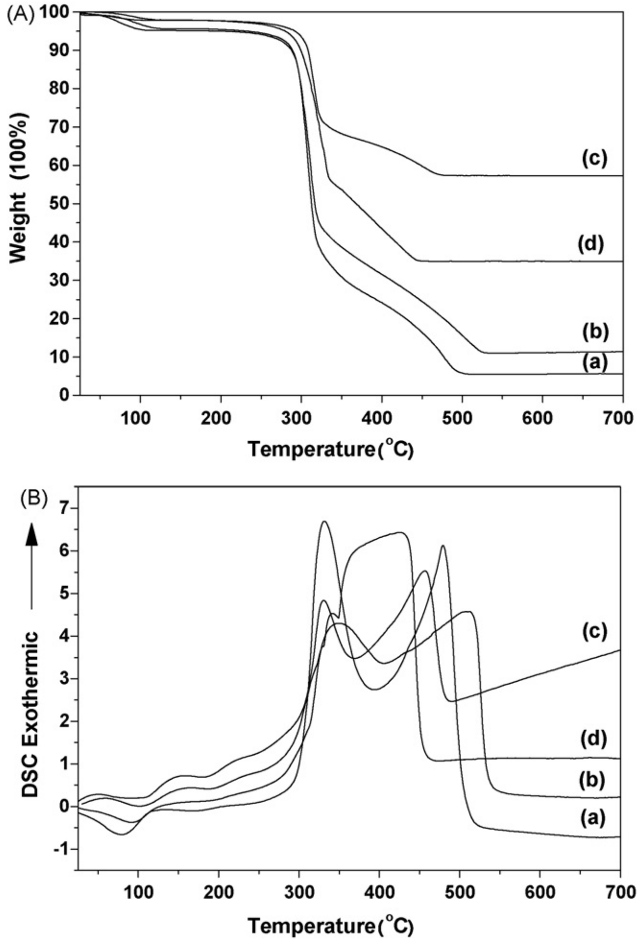


Fig. 4. (A) TG and (B) DSC curves of the typical cellulose-based nanocomposites prepared by microwave heating the DMAc solution of 0.338 g of $AgNO_3$, cellulose solution, and different ascorbic acid concentrations at 150 °C for 40 min. The amounts of ascorbic acid used were: (a) 0.352 g; (b) 1.000 g; (c) 2.000 g; and (d) 3.000 g.

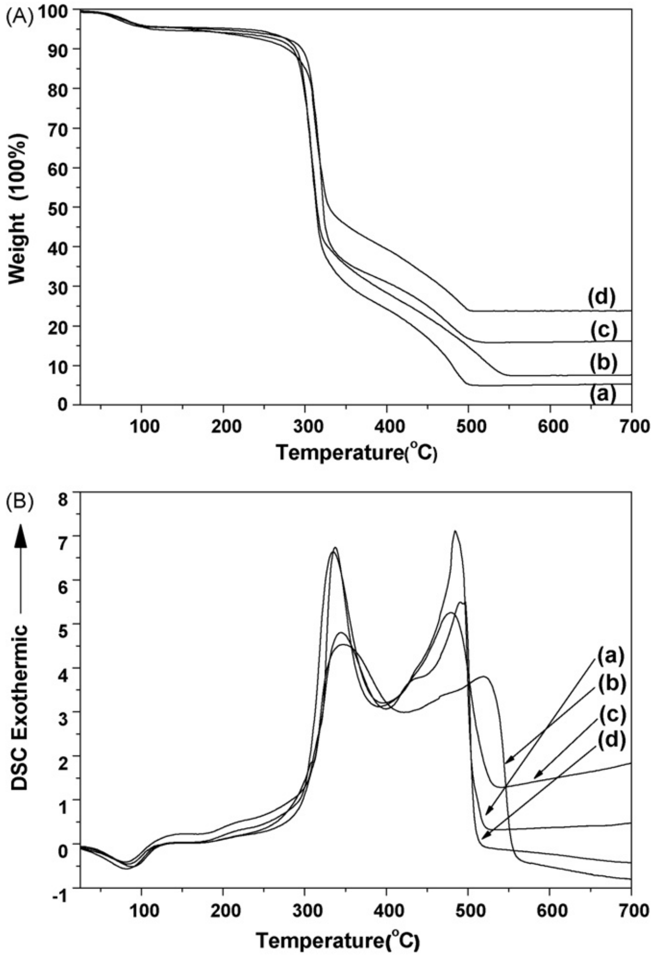


Fig. 5. (A) TG and (B) DSC curves of the typical cellulose-based nanocomposites prepared by oil bath the DMAc solution of 0.338 g of $AgNO_3$, cellulose solution, and different ascorbic acid concentrations at 150 °C for 40 min. The amounts of ascorbic acid used were: (a) 0.352 g; (b) 1.000 g; (c) 2.000 g; and (d) 3.000 g.

mass losses in Fig. 5c and d were very high, compared with those in Fig. 4c and d, implying that the microwave-assisted method is favorable to the synthesis of nanocomposites. The DSC curves also show two obvious broad exothermic peaks located around (332 and 484), (345 and 520), (338 and 480), and (344 and 492) °C (Fig. 5B), respectively. The nanocomposites have similar exothermic peaks between 330 and 350 °C, compared with Fig. 4B. However, one can see that the complete decomposition temperature in the composites prepared by oil bath heating was dramatically increased from 456/431 °C (Fig. 4c and d) to 480/492 °C (Fig. 5c and d), respectively, indicating that the thermal stability of cellulose in the composites by microwave-assisted method decreased. TG/DSC results further indicated the heating method had an influence not only on the phase of nanocomposites, but also on the thermal stability of nanocomposites.

3.4. SEM characterization of the nanocomposites

Fig. 6 shows the SEM micrographs of the cellulose–silver nanocomposites prepared by microwave heating the DMAc solution of 0.338 g of $AgNO_3$, 3.000 g of ascorbic acid, and cellulose solution at 150 °C for 40 min. One can see that silver particles with diameters about 250 nm were homogeneously dispersed in the cellulose matrix. A high magnification image clearly shows the silver particles with polyhedral morphology (Fig. 6b).

Cellulose-based nanocomposite with a larger average nanoparticle size and a broader particle size distribution was obtained by microwave heating at a higher ascorbic acid concentration at 150 °C for 40 min (Fig. 7). For example, the average particle size of AgCl was about 30 nm for the cellulose-based nanocomposite prepared by microwave heating using 0.352 g ascorbic acid at 150 °C for 40 min (Fig. 7a and b). The average particle size of nanoparticles was about 56 nm for the sample prepared by microwave heating using 1.000 g ascorbic acid at 150 °C for 40 min (Fig. 7c and d). When the ascorbic acid amount was increased to 2.000 g, both large and small nanoparticles were observed (Fig. 7e and f). When the ascorbic acid amount was increased to 3.000 g, the silver nanoparticles homogeneously dispersed in the cellulose matrix were obtained (Fig. 6). These results indicated that the ascorbic acid concentration not only had an influence on the phase of the nanocomposites, but also on the size and shape of the nanocomposites.

We also investigated the effect of heating time. When heating time was 10 min (Fig. 8a and b), polyhedral silver particles were dispersed in the cellulose matrix. When the heating time increased to 20 min (Fig. 8c and d), the density of polyhedral silver particles increased. When the heating time increased to 40 min, even more silver particles were homogeneously dispersed in the cellulose matrix (Fig. 6). It can be concluded that enough heating time is a basic requirement for the completion of the silver particle formation.

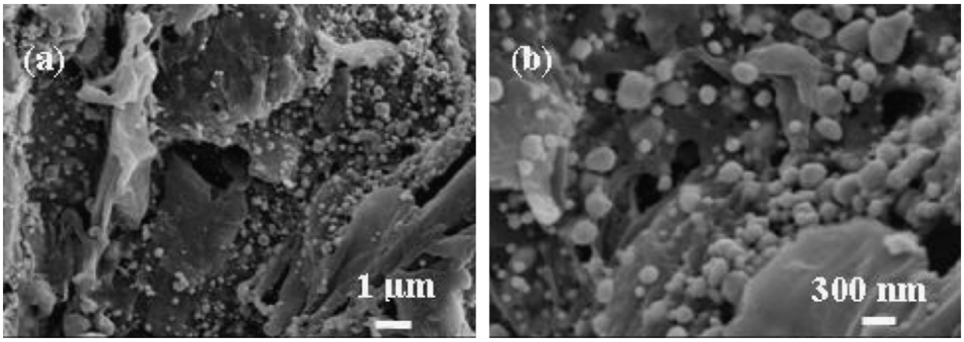


Fig. 6. SEM images of the typical cellulose–silver nanocomposites prepared by microwave heating the DMAc solution of 0.338 g of $AgNO_3$, 3.000 g of ascorbic acid, and cellulose solution at 150 °C for 40 min.

3.5. CP/MAS ^{13}C solid-state NMR analysis

Fig. 9c shows the CP/MAS ^{13}C solid-state NMR spectrum of the cellulose–silver nanocomposites prepared by microwave heating the DMAc solution of 0.338 g of $AgNO_3$, 3.000 g of ascorbic acid, and cellulose solution at 150 °C for 40 min. For comparison, the CP/MAS ^{13}C solid-state NMR spectra of the microcrystalline cellulose and the cellulose–AgCl nanocomposites are also shown in Fig. 9a and b. The starting microcrystalline cellulose display the typical peaks of cellulose backbone at (62.5 + 65.0), (72.4 + 74.8), (84.2 + 88.8), 105.0 ppm relative to the carbons C6, C2–C3–C5, C4, and C1, respectively (Fig. 9a) (Zawadzki & Wisniewski, 2002). Moreover, the small peaks at about 62.5 and 84.2 ppm are the contribution of the disordered regions for C6 and C4 carbons; the peaks at about 65.0 and 88.8 ppm stand for the ordered regions for C6 and C4 carbons, respectively (Liitia, Maunu, & Hortling, 2000). Fig. 9b and c shows the CP/MAS ^{13}C solid-state NMR spectra of the cellulose–AgCl nanocomposites and cellulose–silver nanocomposites, which has

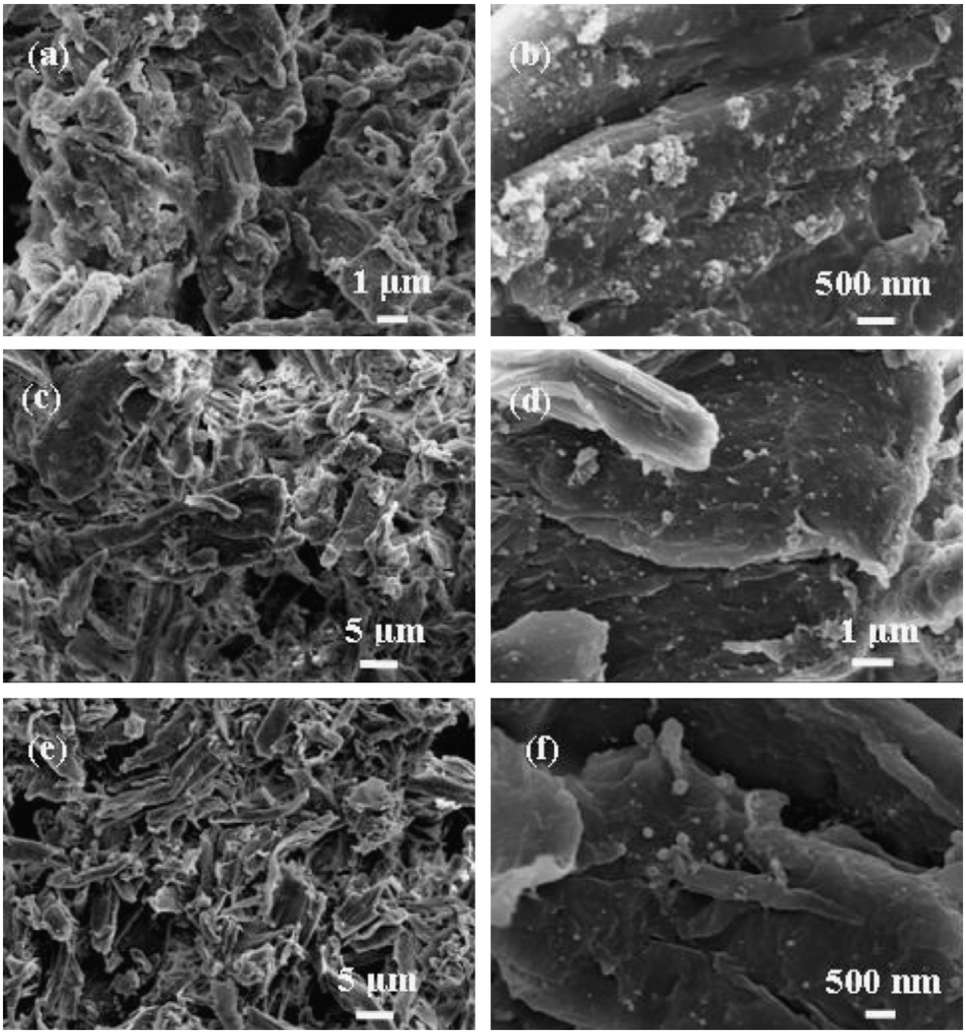


Fig. 7. SEM micrographs of the cellulose-based nanocomposites using different ascorbic acid concentrations compared with Fig. 6. The amounts of ascorbic acid used were: (a and b) 0.352 g; (c and d) 1.000 g; (e and f) 2.000 g.

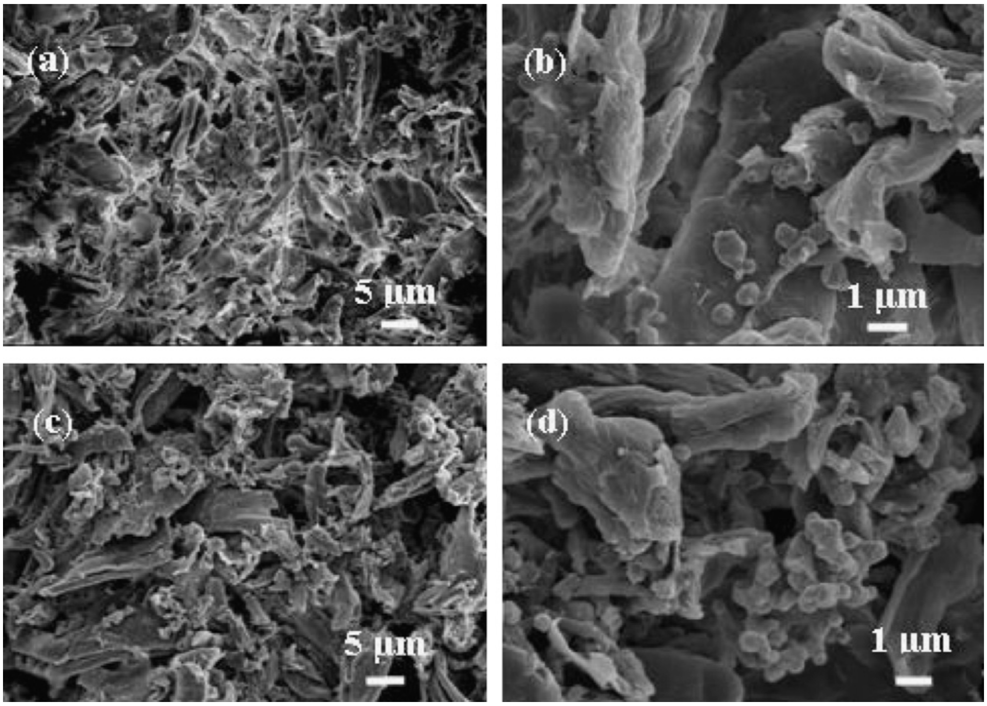


Fig. 8. SEM images of the cellulose–silver nanocomposites with silver nanoparticles dispersed in the cellulose matrix prepared by microwave heating the DMAc solution of 0.338 g of $AgNO_3$, 3.000 g of ascorbic acid, and cellulose solution at 150 °C for different heating times: (a and b) 10 min; (c and d) 20 min.

similar characteristic peaks of cellulose to Fig. 9a. Moreover, the relatively peak intensity of the ordered regions for C6 and C4 carbons in nanocomposite decreased, compared with Fig. 9a, implying that the incorporated nanoparticles lead to a decrease of the crystallinity of the cellulose. The interaction between colloidal Ag particles and cellulose matrix prevents the cellulose chains from assuming an ordered, crystalline arrangement, leading to a decrease in intensity of the cellulose. Similar phenomenon, i.e., a decrease in crystallinity of the cellulose was reported for cellulose–CdS nanocomposites (Ruan et al., 2005), cellulose–Fe_2O_3 nanocomposites (Liu et al., 2008), and cellulose–calcium silicate nanocomposites (Li, Jia, Zhu, Ma, & Sun, 2010).

In the DMAc solution, silver nanoparticles were formed using ascorbic acid as reductant in the cellulose matrix. With the help of the microwave heating, the silver nuclei were formed rapidly. The microwave heating provides the reaction energy to ensure the nucleus formation and growth. Microwave heating is a highly effective heating method, leading to rapid formation of cellulose–silver nanocomposites. One can see that the nanoparticles were embeded in the cellulose matrix and no individual nanoparticles were observed from the SEM results, indicating that the chemical bonds existed in nanocomposites. It is assumed that the colloidal Ag particles are bound to the solid cellulose surface by hydrogen bonding to hydroxyl groups.

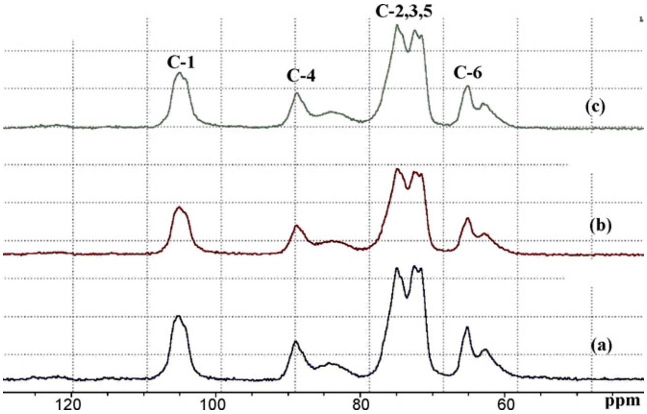


Fig. 9. CP/MAS ^{13}C solid-state NMR spectra of (a) the microcrystalline cellulose, (b) the cellulose–AgCl nanocomposites, and (c) the cellulose–silver nanocomposites.

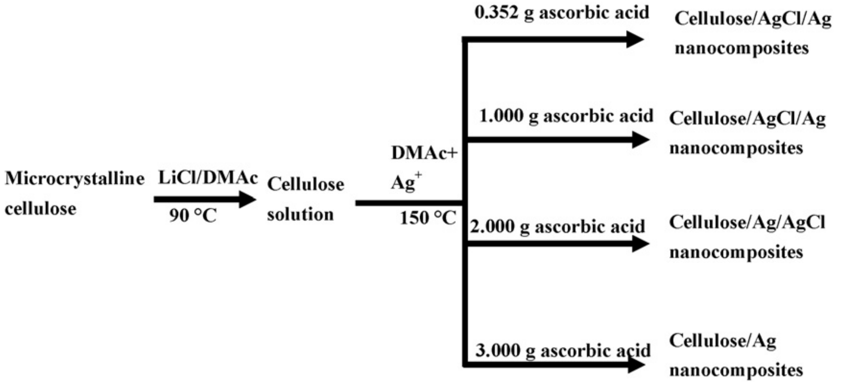
When the ascorbic acid amount was 0.352 g, only litter Ag$^+$ was reduced and the major Ag$^+$ was reacted with Cl$^-$ to fabricate AgCl. So the cellulose–AgCl–silver nanocomposites were obtained. The chemical reactions involved in this process are shown as follows:

$$2Ag^+ + C_6H_8O_6 \rightarrow 2Ag + C_6H_6O_6 + 2H^+ \qquad (1)$$

$$Ag^+ + Cl^- \rightarrow AgCl \qquad (2)$$

The Ag amount increased with increasing the ascorbic acid amount. One can see that the major phase was silver and the AgCl existed as a minor phase, when the ascorbic acid amount was increased to 2.000 g. When the ascorbic acid amount was further increased to 3.000 g, the Ag$^+$ was complete reduced and cellulose–silver nanocomposites were obtained. A scheme for the formation of cellulose-based nanocomposites is shown in Scheme 1.

As a result, microwave heating has an advantage in shortening reaction time. Moreover, the experimental results indicated that different phases were obtained by microwave-assisted and conventional heating. There have been a few reports on the effects of microwave heating on the morphology, size, and size distribution of prepared samples (Natile, Boccaletti, & Glisenti, 2005; Zhu, Wang, Qi, & Hu, 2004) due to its unique thermal and non-thermal microwave effects (Dallinger & Kappe, 2007; De la Hoz, Díaz-Ortiz, & Moreno, 2005). It is generally agreed that the microwave effects (thermal/non-thermal effects) exist in microwave heating reactions (Dallinger & Kappe, 2007). The exact reasons why microwave irradiation is able to improve chemical processes are still unknown and under investigation.



Scheme 1. Illustration for the formation of cellulose-based nanocomposites.

4. Conclusions

In summary, we have described a simple, rapid, and facile microwave-assisted synthesis route to obtain cellulose–silver nanocomposites. In this work, this microwave-assisted method does not need any seed, template or surfactant, thus is a convenient and fast pathway for large-scale and low-cost production of cellulose-based nanocomposites. SEM results indicated that the silver nanoparticles were homogeneously dispersed in the cellulose matrix. The thermal analysis and XRD measurement supported that silver nanoparticles and cellulose were efficiently synthesized. Moreover, the cellulose–silver nanocomposites described here are expected to have good potential performances in functional materials in the future, which can also open a new application for cellulose.

Acknowledgments

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