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Preparation of Drug-loaded Chitosan Microspheres and Its Application in Paper-based PVC Wallpaper

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Abstract. By screening through test, it was found that the drug-loaded chitosan microspheres with the average particle size of 615 nm may be prepared with NaF as the mold-proof drug, chitosan as the drug carrier and sodium tripolyphosphate as the cross-linking agent; and they can improve the aspergillus niger-proof effect if loaded onto the base paper surface of the paper-based PVC wallpaper. The results show that NaF and chitosan have mold-proof synergistic effects; the mold-proof effect of the wallpaper may be improved by increasing the dose of chitosan; when the mass ratio of NaF, sodium tripolyphosphate and chitosan was 2:7:28, the paper-based PVC wallpaper with good mold-proof property can be prepared.

1. Introduction

The paper-based PVC wallpaper is used as an interior wall decoration material. As using plant fiber paper as the base material, it is prone to going moldy in southern China where the weather is rainy and highly humid, which may result in degumming and warping deformation of the wallpaper, affecting the use and the decorative effect of the paper-based PVC wallpaper. Besides, the spores produced by mold can cause some biological pollution to the room air and pose a huge threat to human health [1-3]. As the development of China's wallpaper industry started late, no specific national or industrial standards for the mold-proof property of paper-based PVC wallpaper are available so far. Few domestic and foreign researches focus on the paper-based PVC wallpaper with mold-proof property, and there are only a small number of invention patents [4-8]. Selecting and preparing effective mold-proof agent, and loading it onto the base paper of the wallpaper to prepare the paper-based wallpaper with good mold-proof effect is of great significance to improve the indoor living environment, increase the human health and promote the development of China's interior decoration material industry.

2. Experimental

2.1. Materials

The chemicals like mold-proof agents NaF, CuF_2, $CuSO_4$, $Cu(OH)_2$, $ZnCl_2$, sorbic acid (hereinafter referred to as SA), chitosan (hereinafter referred to as CS) and sodium tripolyphosphate (hereinafter referred to as STPP) were all analytically pure, purchased from Sinopharm Group Chemical Reagent

Co., Ltd.; the aspergillus niger (ATCC-16404) was purchased from Guangdong Institute of Microbiology; the deionized water (H_2O), potato starch medium solution and paper-based PVC wallpaper were self-made by the laboratory.

2.2. Specimen Preparation

The drug-loaded chitosan microspheres were prepared with the ionic cross-linking method by selecting several inorganic mold-proof agents which are less toxic to human, such as NaF, CuF_2, $CuSO_4$, $Cu(OH)_2$ and $ZnCl_2$, as well as the organic mold-proof agent SA as the mold-proof agents, the CS as the drug carrier and STPP as the cross-linking agent. And then, they were coated onto the base paper surface of various drug-loaded chitosan microspheres. The wallpaper samples were placed into the potato starch medium with uniformly-spread aspergillus niger spore liquid. The cultivation lasted for 20 days under the condition with the temperature of 28 ℃ ± 2 ℃ and the relative humidity of 90% ± 5%. During the cultivation, the mold generating condition of the wallpaper was observed and the mold-proof properties of different samples were tested relative to the aspergillus niger, to screen out the drug-loaded chitosan with the best mold-proof effect, and study the synergistic effect of mold-proof agent and chitosan, as well as the influence of the concentration of chitosan preparation formula.

2.3. Characterizations

A certain amount of drug-loaded chitosan emulsion was weighed and dropped onto a copper mesh. After drying, the size and morphology of the drug-loaded chitosan were measured with a JEM-1010 transmission electron microscope (TEM) of JEOL Instruments of Japan.

The drug-loaded chitosan emulsion was measured with Zetasizer Nano-ZS laser particle size analyzer in Malvern of UK and the particle size distribution was analyzed and compared with the particle size obtained through TEM observation.

A certain amount of drug-loaded chitosan emulsion was weighed and centrifuged by high-speed centrifuge solid-liquid separation. And then, the lower sediment solution was taken, and put into a vacuum freeze dryer for 24 hours drying. After the sediment solution was dried, a certain amount of sample was weighed to carry out the analysis on the drug-loaded chitosan using the Nicolet 360 Fourier infrared spectrometer of USA. The tabletting method was used to measure the potassium bromide (KBr). The dried sample and KBr were mixed by a certain mass ratio, ground into powder, and made into slices for measurement. The measured wavelength was set as 4000 cm^{-1} ~ 400 cm^{-1}.

3. Results and Discussion

3.1. Influence of mold-proof agent type on the mold-proof effect of the paper-based PVC wallpaper

Six mold-proof agents with the concentration of 2 g/L were respectively taken by 50 mL, and respectively mixed with the STPP solution with the concentration of 2 g/L. And then, 100 mL CS solution with the concentration of 4 g/L were respectively added into the mixed solution to achieve the cross-linking reaction to prepare six drug-loaded chitosan emulsions with the mass ratio of mold-proof, STPP and CS of 1:1:4, namely CS/NaF, CS/CuF_2, CS/$CuSO_4$, CS/$Cu(OH)_2$ and CS/$ZnCl_2$ and CS/SA. The six drug-loaded chitosan emulsions were coated onto the base paper surface of the paper-based PVC wallpaper. After they were dried, 6 types of wallpaper samples were prepared and the mold-proof test was carried out. Each type of wallpaper samples was divided into 3 groups which were used to conduct the parallel tests to eliminate the error. As seen from Figure 1, the five types of drug-loaded chitosan, including CS/CuF_2, CS/$CuSO_4$, CS/$Cu(OH)_2$, CS/$ZnCl_2$ and CS/SA, as well as the chitosan itself had a poor mold-proof effect; the paper-based PVC wallpapers made by using CS/NaF had the smallest aspergillus niger area. Thus, CS/NaF had a better aspergillus niger-proof effect compared to the other types of chitosan. The CS/NaF emulsion may be selected as a mold-proof agent to perform the mold-proof modification for the paper-based PVC wallpaper and prepare the mold-proof paper-based PVC wallpaper.

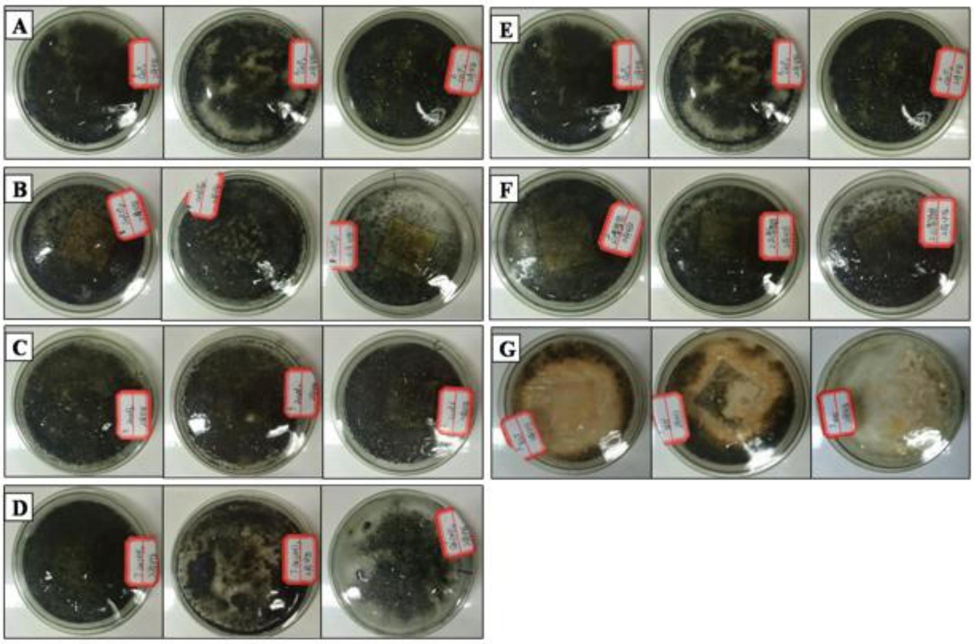

Figure 1. The photographs of different PVC coated wallpaper inoculated mold after 20 days (A. blank; B. $CS/CuSO_4$; C. $CS/ZnCl_2$; D. $CS/Cu(OH)_2$; E. CS/CuF_2; F. CS/SA; G.CS/NaF)

3.2 Analysis on the mold-proof synergic effect of chitosan and sodium fluoride

In order to explore the influence of single factor on the mold-proof effect of the wallpaper, 50 mL CS solution with the concentration of 4 g/L, and 50 mL NaF solution with the concentration of 2 g/L as well as the 50 mL CS/NaF emulsion with the mass ratio of NaF, STPP and CS of 1:1:4 were prepared using the deionized water; the above three solutions were coated onto the base paper surface of the paper-based PVC wallpaper. After they were dried, three types of wallpaper samples were obtained. And then, the mold-proof test was carried out using the three types of wallpaper samples and the blank control sample which were not coated with any solution. Each type of wallpaper samples was divided into 2 groups which were used to conduct the parallel tests to eliminate the error. As seen from Figure 2, CS has less aspergillus niger-proof effect; NaF has certain mold-proof effect; and CS/NaF have the best mold-proof effect. This shows that either using CS or using NaF alone cannot have a good mold-proof effect, the CS/NaF-loaded wallpaper has a good aspergillus niger-proof effect. CS and NaF have mold-proof synergic effect.

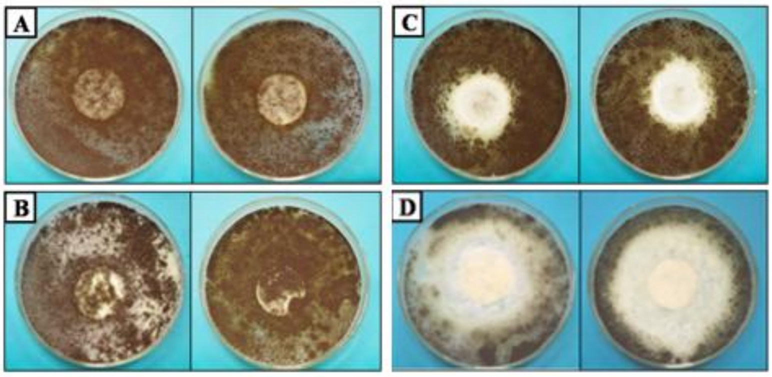

Figure 2. The photographs of different PVC coated wallpaper inoculated mold after 20 days（A. blank; B. CS; C. NaF; D. CS/NaF）

The morphology of CS/NaF was observed using TEM. As shown in Figure 3, CS/NaF basically presented the microsphere morphology with uniform size distribution. The particle size distribution of CS/NaF microspheres was measured using a laser particle size analyzer. As shown in Figure 4, the CS/NaF microspheres have a particle size distribution between 400 nm and 700 nm and an average particle size of 615 nm. The CS/NaF microspheres have a uniform size distribution, which was consistent with the morphology shown in Figure 3.

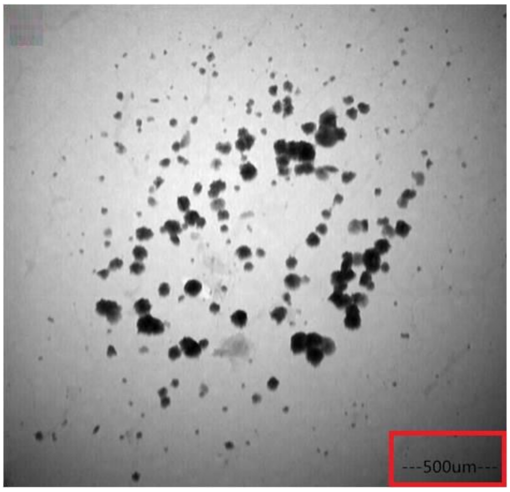

Figure 3. TEM of the sodium fluoride-chitosan complex

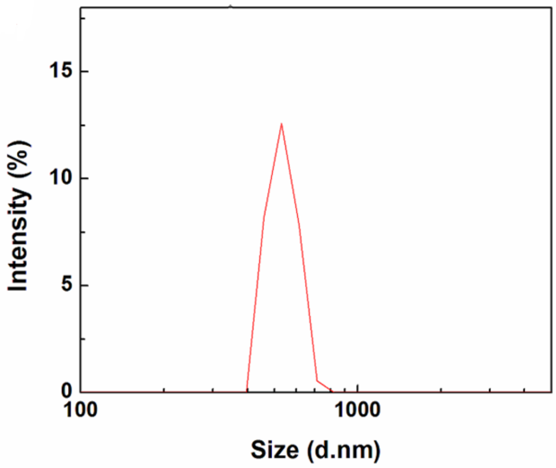

Figure 4. Particle size distribution of the sodium fluoride-chitosan complex

The CS and the prepared CS/NaF microspheres were examined by Fourier infrared spectrometer (FT-IR) to observe the chemical changes of CS before and after microspheres preparation. As shown in Figure 5, the stretching vibration of -OH and C-H bonds of CS appeared at 3387 cm^{-1} and 2876 cm^{-1}, respectively. At the same time, CS contained two characteristic absorption peaks at 1598 cm^{-1} and 1384 cm^{-1}, respectively [9, 10]. Compared with CS, the characteristic absorption peak of CS/NaF shifted to 1576 cm^{-1} and 1412 cm^{-1} in the infrared spectra of CS/NaF after NaF and CS were combined by STPP cross-linking agent. Meanwhile, the -OH bond of CS at 1085 cm^{-1} was moved to 1079 cm^{-1} by cross-linking reaction. From the two absorbance curves of infrared spectra in Figure 5, it can be seen that no new characteristic peak appeared in the CS/NaF spectra compared with the spectra of CS other than the shift of the characteristic peak, which may be due to the influence of NaF or STPP on CS. This shows that the cross-linking of NaF and CS was a physical-change cross-linking mode, and no new chemical was produced; NaF and CS form CS/NaF microspheres under the action of STPP ; the $-NH_2$ bond on the surface of CS was decomposed in acidic conditions, which makes CS solution have a positive charge. And then, the CS solution with positive charges was combined with the STPP with negative charges through the electrostatic interaction to form the drug-loaded chitosan microspheres [11-13].

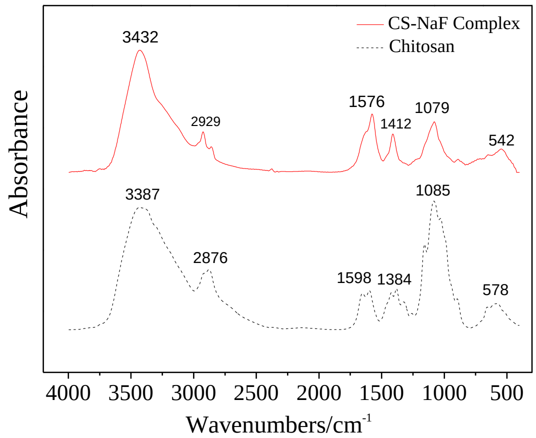

Figure 5. FTIR spectra of chitosan and sodium fluoride-chitosan complex

3.3 Influence of chitosan concentration on the mold-proof effect of the paper-based PVC wallpaper

In order to eliminate the influence of mold-proof drugs on the mold-proof effect of the paper-based PVC wallpaper, the NaF solution with the concentration of 0.5 g/L was prepared first, and then seven CS solutions with different concentrations (4 g/L, 6 g/L, 8 g/L, 10 g/L, 12 g/L, 14 g/L and 16 g/L) and STPP solutions with the concentrations of 2 g/L, L, 5 g/L, 6 g/L, 7 g/L and 8 g/L. 50 mL of NaF solution with the concentration of 0.5 g/L was first taken as the mold-proof drug, and then, 50 mL STPP solution with different concentrations were respectively taken as the cross-linking agents. Finally, 100 mL CS solution with different concentrations were taken as carrier. After the solutions were mixed, seven CS/NaF microsphere emulsions with the mass ratio of NaF, STPP and CS respectively 1:4:16, 1:6:24, 1:8:32, 1:10:40, 1:12:48, 1:14:56 and 1:16:64 were prepared. The seven CS/NaF microsphere emulsions were coated onto the base paper surface of the paper-based PVC wallpaper to obtain seven CS/NaF-loaded wallpaper samples after drying. The aspergillus niger-proof test was carried out using the seven CS/NaF-loaded wallpaper samples and the blank control samples.

As seen from Figure 6, the mold area of aspergillus niger decreases with the increase of the CS concentration in the raw material; the wallpaper samples prepared using the CS solution with the concentration of $\leq$ 12 g/L have less aspergillus niger-proof effect. In the samples g and n prepared using the mass ratios of NaF, STPP and CS of 1:14:56 and 1:16:64 almost had no mold spot and the aspergillus niger area at the blank area of the medium surrounding the samples decreases with the increase of the concentration of CS solution in the raw material. This shows that using the CS solution with the concentration $\geq$ 14 g/L in the raw material to prepare the wallpaper has a good aspergillus niger-proof effect. The increase of CS concentration improved the mold-proof property of the drug-loaded chitosan. This may be attributed to the increase of the number of CS molecules, which increases the probability of NaF entering the interior of the microspheres. During drying of the wallpaper after coating, the presence of CS can reduce the volatilization of NaF, thereby increasing the retention of NaF on the base paper of the wallpaper.

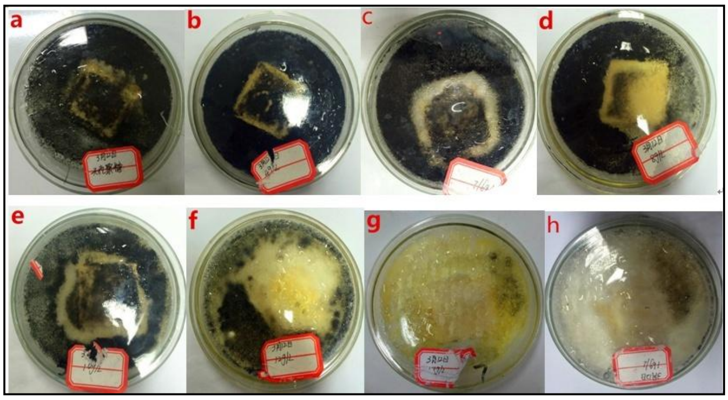

Figure 6. The photographs of PVC coated wallpaper loaded by different concentration of the chitosan inoculated mold after 20 days (a. blank; b. 4 g/L CS; c. 6 g/L CS; d. 8 g/L CS; e. 10 g/L CS; f. 12 g/L CS; g. 14 g/L CS; h. 16 g/L CS)

Due to the wide availability and low cost of CS raw materials, a high concentration of CS solution can be used as a carrier in order to prepare the best anti-mildew paper-based PVC wallpaper. 100 mL of CS solution with the concentration of 14 g/L was taken as the carrier, 50 mL of 2 g/L NaF solution as the antifungal drug and 50 mL of STPP solution with the concentration of 7 g/L as the crosslinking agent. After mixing, the CS/NaF microsphere emulsion with mass ratio of NaF, STPP and CS of 2:7:28 was prepared. The CS/NaF microsphere emulsion was coated onto the base paper surface of the paper-based PVC wallpaper to prepare CS/NaF-loaded mold-proof wallpaper after drying. The aspergillus niger-proof test was carried out. As seen from Figure 7, no mold spot was found on the surface and surroundings of the mold-proof wallpaper samples 20 days after inoculated with aspergillus niger, showing a good mold-proof effect.

4. Conclusions

The wallpaper prepared with NaF as the mold-proof drug has a good aspergillus niger-proof effect compared to other mold-proof agents.

Through the research of the influence of individual variable on the mold-proof effect, it was found that the sample only loaded with CS has no aspergillus niger-proof effect, the sample only loaded with NaF has a certain mold-proof effect, and the sample loaded with CS/NaF microspheres has the best aspergillus niger-proof effect, showing the mold-proof synergistic effect of NaF and CS.

In the process of preparation of drug-loaded chitosan, increasing the dose of CS can improve the mold-proof effect of the wallpaper; when the mass ratio of NaF, STPP and CS was 1:14:56, the wallpaper has the best aspergillus niger-proof; when the mass ratio of NaF, STPP and CS was 2:7:28, the mold-proof paper-based PVC wallpaper can be prepared, and the aspergillus niger-proof area can reached 100%, showing the best mold-proof effect.

Through the TEM observation, the CS/NaF mixture showed microsphere morphology. The measurement of the laser particle size analyzer showed that CS/NaF microspheres had a uniform particle size distribution with an average particle size of 615 nm. The characterization of Fourier infrared spectrometer showed that CS and NaF formed CS/NaF microspheres in the form of physical cross-linking under the action of STPP. CS/NaF microspheres were more likely to adhere to the base paper of wallpaper compared to NaF, which increased the retention of NaF on the wallpaper, thereby increasing the mold-proof property of the paper-based PVC wallpaper.

Acknowledgments

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