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Original research article

Combined analysis of static and dynamic extinction characteristics of microbial spores and mycelia as a mid-infrared extinction material

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ABSTRACT

The extinction characteristics of microbial materials have always played an important role in identification of microbial materials. To evaluate the extinction properties of microbial materials comprehensively, a method via combined static and dynamics analysis extinction performance is presented, combining with the reflection spectra measured by a Nicolet FT-IR spectrometer, and transmittance determined by smoke box test of microbial materials in $3 \sim 5\ \mu m$. In the case of static analysis, the complex refractive indices of microbial spores and mycelia were retrieved by using Kramers-Kronig (KK) transform and an iterative method on the basis of the reflection spectrum exponential extrapolation method. Based on Mie theory, the mass extinction coefficients of microbial spores are 15.58%, 28.07%, and 36.72% greater than those of the corresponding mycelia respectively. While in the dynamic analysis, in the terms of Beer-Lambert law, the mass extinction coefficients of microbial spores are 31.83%, 21.63%, and 68.42% greater than those of the corresponding mycelia respectively. It is shown that mid-infrared extinction performance of microbial spores are always better than those of corresponding microbial mycelia. The results show that the method is practicable and play an important role in finding strong mid-infrared extinction microbial materials.

1. Introduction

Extinction generally occurs whenever the propagation of an electromagnetic wave through a material medium containing small particles is generated. The spectral dependence of extinction is a function of the structure, complex refractive index and size distribution of the particles. The extinction efficiency of microbial materials is dependent on particle size, composition of microbes and wavelength of incident radiation. Traditional inorganic materials are widely used as extinction materials in the field of aerospace, medicine, opto-electronic and so on, which include graphite [1–3], silicide [4–8], copper powder [9–17], and so forth. However, these materials have many disadvantages, such as expensive, low generation efficiency, narrow extinction band, environmental contamination, and so on. The shortcomings above-mentioned have restricted their future development of inorganic extinction materials to a certain extent. Recently, considerable attention has been paid to the development of high-efficiency extinction materials with light weight, wide bandwidth, low cost, and strong extinction characteristics. Microbial materials have a lot of advantages, such as short growth cycle, low production cost, abundant form, wide size distribution, and absence of toxic or harmful

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irritants in the casting process. Relevant research have been carried out by the scholars at home and abroad [18–28].

In this study, six microbial materials, which are fungal Am0305 spores, fungal Am0305 mycelia, fungal Bn0512 spores, fungal Bn0512 mycelia, fungal Cv0723 spores, and fungal Cv0723 mycelia, were cultured. In the case of static analysis, the reflectance spectra were obtained from 4000 to 667 cm^{-1} by using Fourier transform infrared spectrometer. Complex refractive index $m = n + ik$ of microbial materials were calculated based on KK relation [29–37] based on the measured reflectance spectra data in the range of 3 ~ 5 μm. The error of reflectance retrieved based on different incident angle was analyzed. The extinction coefficients of different microbial materials were obtained based on Mie theory [37–39]. While in the procedure of dynamic analysis, a smoke box experimental system was built to measure the transmittance of fungal spores and mycelia. The dynamic mass extinction coefficients of fungal spores and mycelia were obtained in terms of Beer-Lambert law. The results both show that microbial spores have always better extinction properties than microbial mycelia in 3 ~ 5 μm. It shows that it is a practicable method to obtain the strong mid-infrared extinction materials by using combined analysis of static and dynamic extinction performance of microbial materials.

2. Experimental

2.1. Materials preparation

Six Microbial materials were prepared by ourselves, which were fungal Am0305 spores, Am0305 mycelia, Bn0512 spores, Bn0512 mycelia, Cv0723 spores, and Cv0723 mycelia respectively. Potato dextrose agar (PDA) slants, which were composed of 200 g/L potato, 20 g/L glucose, and 20 g/L agar, were used to culture all fungi above mentioned at 26 °C for 7 days, respectively. All prepared microbes were stored at 4 °C until further use [40]. The spores, which were obtained from the PDA slant, were suspended in sterile water and two layers of gauze were used to filter spores in sterile water twice to eliminate any mycelial fragments, followed by dilution with sterile water to 1.0×10^8 spores/mL. Then, 2 mL of the spore suspension were inoculated into a 500 mL Erlenmeyer flask containing 100 mL of PDA liquid medium and incubated in a rotatory shaker at 170 r/min and 26 °C for 2 days. Thereafter, two layers of gauze were utilized to filter the fermentation broth and the mycelia were achieved by washing filtered fermentation broth three times with tap water. A loop of microbial cultures from the slant was put into eggplant-like flasks containing 50 mL of PDA solid medium and incubated at 26 °C for 7 days for spore production, respectively. 0.01% Tween-80 was used to wash out the fungal spores, which were filtered via two layers of gauze. Subsequently, A 50 mL centrifuge tube was serve as a vessel to load the filtrate, which was centrifuged three times for 10 min at 8000 r/min to get rid of the sediments [25].

2.2. A method of static reflectance measurement

Infrared spectroscopy was performed on a micro-IR spectrometer in the static test. A certain number of microbial materials samples are weighed and broken up by grinding bowl. Then, the samples tablets of microbial materials are achieved by powder tablet press. A FT-IR spectrometer was applied to measure the reflection spectra from 667 to 4000$\boldsymbol{cm}^{-1}$. In the procedure of reflectance measurement, incident angle was set to 18 ° and average reflectance of three sampling points from each sample tablet was used to define the specular reflection spectrum. In order to obtain the approximately ideal specular reflection spectra, the optically clean, inclusion-free, smooth, and crack-free areas in the spot were selected to measure. The detailed procedure of reflectance measurement was published by the literature [22,40,41].

2.3. A method of dynamic transmittance measurement

Infrared transmittance of microbial materials was performed by a dynamic test based on a self-designed smoke box experimental system. A smoke box experimental system was made up of a smoke box, spraying system, test system, concentration sampling system, and exhaust system. A smoke box, spraying system, and exhaust system were home-made. Every component and its function of smoke box experimental system were described in detail in the literature [41]. In the procedure of dynamic transmittance measurement, the transmittance of smoke materials could be derived in the light of measurements of the smoke materials before and after the radiation intensity of the infrared thermal imager, which revealed the extinction effects of smoke materials on the target radiation source [26].

3. Results and discussion

3.1. Measurement of reflectance

It is well known that reflectance of a material is its effectiveness in reflecting radiant energy. It is the fraction of incident electromagnetic power that is reflected at an interface. The reflectance spectrum or spectral reflectance curve is the plot of the reflectance as a function of wavelength. Reflectance is an important concept in the fields of optics. As well, reflectance is an important data used to obtain the optical constant of materials. According the measurement method of reflection spectra above mentioned, the specular reflectance spectra of six microbial materials are shown in Fig. 1.

3.2. Exponential extrapolation of reflectance

Based on the method of static reflectance measurement, the reflection spectra of microbes in the range of 2.5 through 15$\boldsymbol{\mu m}$ were