

Experimental study on extinction performance of carbon nanotubes smoke to infrared radiation

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Abstract. Carbon nanotubes are one of the most typical materials in the nanoscale world. In order to study the IR interference performance of carbon nanotubes as smoke agent, using indoor large smoke box, the infrared extinction performance of three kinds of carbon nanotubes were measured in 8 μm ~12 μm band. The smoke forming performance of carbon nanotubes were obtained by means of the testing of smoke mass concentration. Based on the experimental data, the dynamic mass extinction coefficients of three kinds of carbon nanotubes were calculated. The results show that carbon nanotubes smoke have good extinction performance to infrared radiation.

1. Introduction

Since the discovery of carbon nanotubes in 1991, the excellent physical and chemical properties of carbon nanotubes have aroused great interest and research upsurge. At present, the synthesis technology of carbon nanotubes has matured, especially the carbon nanotubes can be produced by chemical vapor flow catalytic method[1-3]. Both theoretical and experimental results show that the carbon nanotubes have specific properties, and the application prospect is immeasurable. Carbon nanotubes not only have the characteristics of small size effect, surface effect, quantum size effect and so on, and the unique spiral, tubular structure, high conductivity and electromagnetic loss tangent angle, making it also has than other nano materials more superior and unique wave absorbing properties and has a very broad application prospects. Preliminary study shows that the carbon nanotubes not only have a good absorption property for microwave, but also have a good absorption property in the infrared band[4-5]. The absorbing material, which is made of carbon nanotubes as absorbent, has the characteristics of wide frequency bandwidth, controllable, good compatibility and so on. It is a new generation of absorbing material with great potential. Preliminary results have been achieved in the application of the coating stealth field, but the study of carbon nanotubes as smoke agent to interfere infrared radiation, has rarely been reported in the literature.

In view of the carbon nanotubes have many advantages such as small scale, light weight, excellent levitation characteristics in the air and large specific surface area, absorption and scattering of electromagnetic wave in a wide band, etc. We carried out carbon nanotubes as smoke agent interfering materials research on anti infrared radiation. The extinction characteristics of several kinds of carbon nanotubes smoke were tested in the 8 μm ~12 μm band.

2. Measurement principle of mass extinction coefficient

Scattering and absorbing of smoke agent on infrared radiation totally called extinction. The extinction properties commonly described using mass extinction coefficient α (m^2/g), which is defined as the



extinction cross section per unit mass of smoke particles. The greater the extinction coefficient of the material becomes, the better the attenuation effect of infrared radiation will be. Define I_0 as infrared radiation incident intensity, through the smoke the strength is I , according to the Lambert-Beer law:

$$T = \frac{I}{I_0} = I_0 \exp(-\alpha C_m L) \quad (1)$$

Where, T is transmission rate, C_m is smoke mass concentration(g/m^3), L is optical path(m). From the above expression, the smoke concentration and path under certain circumstances, for a certain intensity of infrared radiation, the transmission rate is determined by the mass extinction coefficient α , so, α is an important parameter for evaluating smoke extinction performance. According to formula (1), the calculation formula of mass extinction coefficient can be obtained:

$$\alpha = \frac{1}{C_m L} \ln \frac{I}{T} \quad (2)$$

Therefore, in the case of the known optical path, through the measurement of infrared radiation transmittance and smoke mass concentration, the values of smoke material mass extinction coefficient α can be obtained.

3. Test system

Test system shown in figure 1. The main test equipment is as follows:

Smoke box. The volume is 20m^3 ($6.1\text{m} \times 2\text{m} \times 1.8\text{m}$), optical path $L = 6.1\text{m}$, two built-in mixing fan.

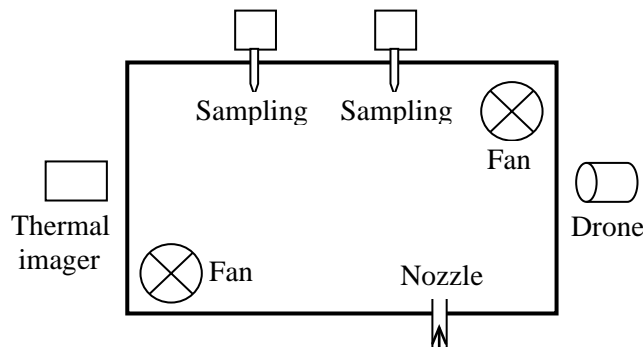


Figure 1. The test system of smoke box

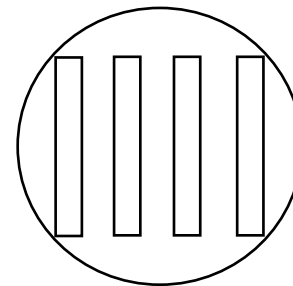


Figure 2. The structure of drone

Filter membrane concentration sampling system. The mass concentration of smoke is weighed by membrane weighing method. Extracting a volume of smoke in the smoke box, making it through the glass fiber filters, the smoke particles are blocked in the filter paper, according to the ratio of membrane added mass to the sampling smoke volume, calculating the mass concentration of smoke solid particles. The calculation formula is as follows:

$$C_m = (m_1 - m_2) / Q \quad (3)$$

Where, m_1 is the value of the filtration membrane quality after sampling, m_2 is the value of the filtration membrane quality before sampling, Q is sampling flow, its value is $40\text{L}/\text{min}$. In order to make the mass sampling concentration representative, in the different positions of smoke box testing light path set two sampling pump, at the same time sampling, and the average value is the smoke mass concentration. Sampling time is 1 minutes, a total of three times of sampling, the interval is 2 minutes.

Drone. Drone provides an infrared heat source with a constant temperature difference of 30°C at room temperature, the temperature control precision is $\pm 0.01^\circ\text{C}$, the drone shape is shown in Figure 2. The infrared heat radiated by drone pass through the smoke box and received by the infrared thermal imager. Finally, infrared thermal image of drone are formed on the monitor.

Thermal Imager. Working waveband $8\mu\text{m} \sim 12\mu\text{m}$, external video recorder and monitor.

Drone and infrared thermal imager are arranged at both ends of the smoke box, the infrared thermal image of the drone in the absence of interference, after being accepted by the thermal imager, a clear infrared image of black and white of the drone on the monitor. After spraying smoke material, using the absorption and scattering of smoke particles to drone infrared radiation energy, eliminate difference between drone and background infrared radiation, so that the infrared thermal imager can't form normal infrared drone image, the shielding condition of smoke to infrared drone image can be visually observed on the monitor, according to the drone image gray value at different times. The transmittance curve can be obtained through the quantitative calculation of smoke transmittance.

4. Test result

There are three kinds of carbon nanotubes used in the test, the size and the performance parameters are shown in Table 1.

Table 1. The performance parameters of carbon nanotubes.

Sample number	Material name	Diameter(nm)	Length(μm)	specific surface area ($\text{m}^2\cdot\text{g}^{-1}$)
①	carbon nanotubes	10-30	1-2	40-300
②	carbon nanotubes	40-60	1-2	40-300
③	carbon nanotubes	60-100	5-15	40-300

4.1. Smoke mass concentration

Weighing each size of materials 20g, using the high-pressure airflow sprayed into the smoke box, through sampling, weighing, the smoke mass concentration at different time is calculated according to equation (3), as shown in Table 2.

Table 2. The test results of smoke mass concentration.

Sample number	Sampling sequence	mass concentration C_m ($\text{g}\cdot\text{m}^3$)		\bar{C}_m ($\text{g}\cdot\text{m}^3$)
		C_1	C_2	
①	1	0.392	0.516	0.454
	2	0.279	0.335	0.307
	3	0.178	0.253	0.215
②	1	0.443	0.559	0.501
	2	0.215	0.202	0.208
	3	0.106	0.150	0.128
③	1	0.315	0.429	0.372
	2	0.197	0.266	0.232
	3	0.141	0.168	0.154

For some smoke interference materials, the effect of interference is more obvious when the smoke mass concentration becomes higher, which the number of smoke particles is more in the unit volume. So, to improve the smoke mass concentration can improve the overall effect of the smoke extinction. As shown in table 2, the smoke mass concentration formed by ① and ② carbon nanotubes higher than the ③ carbon nanotube. It is concluded that the thin and short carbon nanotubes have good performance of smoke forming.

4.2. Shielding of infrared drone

When the carbon nanotubes are not sprayed, the infrared target is clearly visible on the monitor, as shown in Figure 3 (a). After spraying 20g carbon nanotube materials in the smoke box, as a result of scattering and absorption of infrared radiation by carbon nanotubes, the thermal imager to receive the infrared drone image is disturbed, the image becomes fuzzy straight completely disappear, figure 3 (b) for the drone image is completely covered. With the passage of time, due to the smoke particles of natural sedimentation, so that the smoke concentration decreased gradually in the smoke chamber, and the shadowing effect weakening, the drone image on the monitor gradually emerge and clear, figure 3 (c) is the drone image after the appearance.

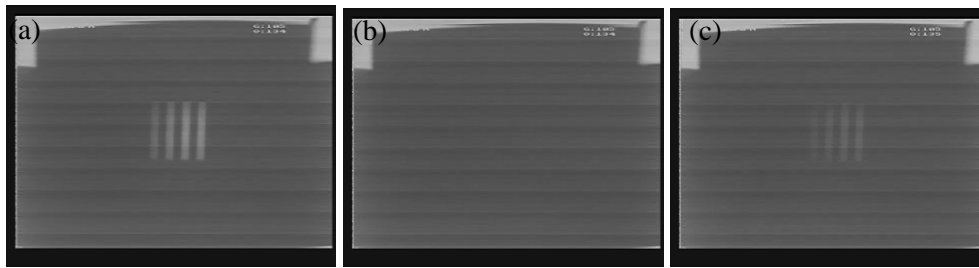


Figure 3. The shielding of carbon nanotubes smoke to IR drone.(a) Original drone image;(b) The image when smoke completely obscured drone; (c) The image after appearance of drone

4.3. Transmission rate

The thermal imager infrared detector output signal is proportional to the received irradiance. Therefore, ray intensity on the CRT screen is also proportional to the irradiance received by detector, strong radiation at high temperature parts, corresponding to the infrared thermal images bright parts, low-temperature parts corresponding to grey area. Therefore, according to the gray image formed by thermal imager, the smoke transmission on infrared radiation can be calculated by the following formula:

$$T = \frac{h_2(t) - h_1(t)}{h_2(0) - h_1(0)} \times 100\% \quad (4)$$

Where, $h_1(0)$ and $h_1(t)$ respectively represent the gray value of the dark zone of infrared thermal images before and after throwing up a smokescreen, $h_2(0)$ and $h_2(t)$ respectively represent the gray value of the bright zone of infrared thermal images before and after throwing up a smokescreen. Select an infrared thermal image interval of 10s and to calculate the arithmetic mean value of the corresponding transmission rate of each part of the drone as the transmittance. The smoke transmission curve of three kinds of carbon nanotubes is shown in Figure 4.

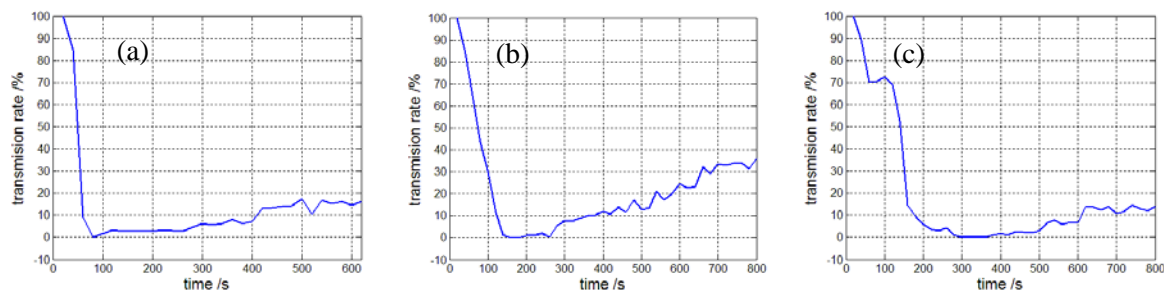


Figure 4. The transmission rate curve. (a) sample ①; (b) sample ②; (c) sample ③

4.4. Mass extinction coefficients

According to the smoke mass concentration shown in Table 2 and the corresponding average transmission rate, the mass extinction coefficients can be calculated based on equation (2). Table 3 is

the mass extinction coefficient of three kinds of carbon nanotubes in 8 μm ~12 μm wave band at different time. As can be noted from table 3, the mass extinction coefficient of the three carbon nanotube materials are all greater than 1 $\text{m}^2\cdot\text{g}^{-1}$. The mass extinction coefficient of Sample ③ is greater than those sample ① and sample ②.

Table 3. Infrared extinction coefficients of carbon nanotubes smoke to 8 μm ~12 μm .

Sample number	Time /s	$C_{\text{m}}/\text{g}\cdot\text{m}^{-3}$	$T / \%$	$\alpha / \text{m}^2\cdot\text{g}^{-1}$	$\bar{\alpha} / \text{m}^2\cdot\text{g}^{-1}$
①	1~2	0.454	2.6813	1.3067	1.4086
	4~5	0.307	6.8382	1.4325	
	7~8	0.215	14.2310	1.4867	
②	1~2	0.501	1.2970	1.4218	1.4755
	4~5	0.208	14.3384	1.5308	
	7~8	0.128	31.8129	1.4668	
③	1~2	0.372	1.3186	1.9075	1.9519
	4~5	0.232	6.6938	1.9107	
	7~8	0.154	14.2613	2.0733	

5. Conclusions

Based on the Lambert Beer law, infrared interference extinction performance of three kinds of carbon nanotubes in 8 μm ~12 μm wave band have been tested using indoor smoke box. The mass extinction coefficients in this wave band are 1.4086 m^2/g 、1.4755 m^2/g and 1.9519 m^2/g respectively. It shows that the carbon nanotube material has a good infrared extinction performance. Although the thin and short carbon nanotubes sample ① and sample ② have better performance in forming smoke than sample ③, but the mass extinction coefficient is lower than sample ③. Although the mass extinction coefficient of carbon nanotube sample ③ is big, the mass concentration in the smoke box is not high, the maximum value is 0.372 $\text{g}\cdot\text{m}^{-3}$, and with the increase of time decreased significantly. It shows that the smoke forming and suspension performance of carbon nanotube material need to be further improved.

References

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