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Electromagnetic wave absorbing properties of multi-walled carbon nanotube/cement composites

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HIGHLIGHTS

- We studied the wave absorbing properties of MWCNT/cement composites.
- 0.6 wt.% MWCNTs can improve the wave absorbing properties of cement composites.
- 0.9 wt.% MWCNTs make the bandwidth below −10 dB reach 7.1 GHz between 8 and 18 GHz.

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ABSTRACT

The electromagnetic wave absorbing properties of multi-walled carbon nanotube (MWCNT)/cement composites were studied. The influence of the MWCNT content and sample thickness on the electromagnetic wave reflectivity was discussed and analyzed in the frequency ranges of 2–8 GHz and 8–18 GHz. When the MWCNT content is 0.6 wt.%, the cement mortar sample with a thickness of 25 mm can remarkably absorb electromagnetic waves close to the absorbing peaks in the frequency range of 2–8 GHz. The strongest peak with a reflectivity of −28 dB is obtained at 2.9 GHz. The cement mortar sample with a thickness of 35 mm presents beneficial broadband wave absorption performance between 8 and 18 GHz. The addition of 0.9 wt.% MWCNTs can notably enhance the wave absorption performance of the cement mortar and make the bandwidth below −10 dB reach 7.1 GHz in the frequency range of 8–18 GHz.

1. Introduction

With the rapid development of electrical and electronic devices, such as automobile communication systems, computers, mobile phones and other electronic products, electromagnetic interference (EMI) has become an increasingly serious concern in recent years. Considerable amounts of electromagnetic radiation may be harmful to human health and may affect the normal operation of electronic devices [1]. Therefore, materials for EMI protection have attracted considerable research attention for commercial applications, as well as for military stealth applications because of the demand for deterring electromagnetic forms of spying for military purposes [2].

Cement is commonly used in engineering construction all around the world. However, cement has poor EMI protective properties. It is possible to shield or absorb some electromagnetic waves through conductive introductions [3], and a substantial amount research has been conducted on the development of cement electromagnetic shielding and absorbing materials in recent years. The most widely used fillers are fibers, ferrites and metal powders [4–8]. In addition, materials that possess a cavity structure, such as fly ash floating beads and expanded polystyrene, have been investigated as resonant materials to mix into the cement matrix [9–11]. Carbon nanotubes (CNTs), as a nanoscale material, have been extensively studied in the field of EMI protection due to their high aspect ratio, large specific surface area and superior electrical conductivity [12–15]. Furthermore, CNTs have shown potential for applications in both microwave radiation protection and military stealth applications. However, there are few studies on the EMI protection effect of CNT/cement composites. Nam et al. [16] investigated the EMI shielding effectiveness (SE) of multi-walled carbon nanotube (MWCNT)/cement composites. In their study, MWCNTs were dispersed using ultrasonic processing and poly(sodium-4-styrenesulfonate) was used as a surfactant. The most effective shielding performance at a frequency range from 0.1 to 18 GHz was attained with 1.5 wt.% MWCNTs. Moreover, they used silica fumes to disperse the MWCNTs and reported that the cement matrix with 0.6 wt.% MWCNTs and 20 wt.% silica fume exhibits the best EMI SE in the overall frequency range [17]. Compared with EMI shielding

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Table 1
The physical parameters of the MWCNTs.

Products	Outer diameter (nm)	Length (μm)	Purity (%)	Special surface area ($m^2\,g^{-1}$)
MWCNTs	20–40	5–15	>97	90–120

Table 2
Chemical composition of the cement.

CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	Na_2O
61.13	21.45	5.24	2.89	2.50	2.08	0.77

Table 3
Elementary physical and mechanical properties of the cement.

Loss on ignition (%)	Setting time (min)		Specific surface area ($m^2\,kg^{-1}$)	Flexural strength (MPa)		Compressive strength (MPa)	
	Initial setting	Final setting		3d	28d	3d	28d
3.52	187	239	330	6.0	8.2	28.5	52.5

materials, wave absorbing materials can eliminate or weaken EMI radiation, thus further attenuating electromagnetic radiation by converting the electromagnetic energy to other forms of energy. Until now, however, the effects of MWCNTs on the electromagnetic wave absorbing properties of cement matrix composites have not been widely studied.

In this study, the absorbing electromagnetic wave properties of MWCNT/cement composites were investigated in the frequency ranges of 2–8 GHz and 8–18 GHz. The dispersibility of MWCNTs is one of the key factors that affects the wave absorption properties of MWCNT/cement composites. To incorporate MWCNTs into cement matrix materials, MWCNTs were first dispersed using an ultrasonic processing method with anionic gum arabic (GA).

2. Experimental procedure

2.1. Materials

Chemical vapor deposition-processed MWCNTs were used in our work (provided by Shenzhen NANO-Technology Co., Ltd.). Their physical parameters, structure and morphology are shown in Table 1 and Fig. 1. The cement used was Type P·O 42.5 R Portland cement (produced by Dalian Onoda Cement Co., Ltd.), and its chemical composition and physical properties are shown in Tables 2 and 3, respectively. The water reducing agent was polycarboxylic superplasticizer (produced by Dalian Mingyuanquan Science and Technology Development Co., Ltd.). The dispersant was GA with a viscosity of 60–130 cPa s (supplied by Sinopharm Chemical Reagent Co., Ltd.). The fine aggregate was China ISO Standard Sand with the execution criterion of GSB08-1337-2001 (from Xiamen ISO Standard Sand Co., Ltd.). The defoamer was liquid tributyl phosphate (supplied by Tianjin Chemical Reagent Plant, China). Distilled water was used during the experiment.

2.2. Sample preparation

The water/cement/sand ratio by weight of the specimens was selected as 0.35:1:1.5, and the MWCNTs were incorporated at concentrations of 0.1%, 0.3%, 0.6%, and 0.9% by weight of cement. The mass ratio of MWCNTs to the GA dispersant was 1:6 in each matrix mixture. Reference samples were also prepared for comparison. To ensure workability of the admixture, 1.0% by weight of cement of the water reducing agent was added. The proportions of each component in the mixtures for different samples are listed in Table 4.

MWCNTs were dispersed using a surfactant-ultrasonic method with GA. According to previous test results [18], the relevant dispersant was first dissolved in four-fifths of the total amount of water in each mixture. Then, the weighed MWCNTs were placed into the aqueous dispersant solutions and dispersed sufficiently in an ultrasound processor (DS-3510DT) for 30 min at room temperature; the frequency and power of the ultrasound processor were 40 kHz and 180 W, respectively. Finally, 0.13 vol.% of defoamer was used to eliminate air bubbles in the solutions.

The prepared dispersed mixture and the remaining water were poured into a mixer, and then the cement, sand, and water reducing agent were added. The mixture was slowly stirred for the first 2 min, followed by rapid stirring for 4 min. Afterwards, the prepared mixture was poured into oiled molds and vibrated to remove air bubbles. Samples with sections that had an area of 200×200 mm and thicknesses of 15, 25 and 35 mm were prepared for the reflectivity measurements. The specimens were removed from their molds after 24 h and cured in a moist room (relative humidity $\geqslant$97%) for 28 days.

2.3. Testing method

The reflectivity of the specimens was tested in an anechoic chamber using the arched testing method with an Agilent 8720B

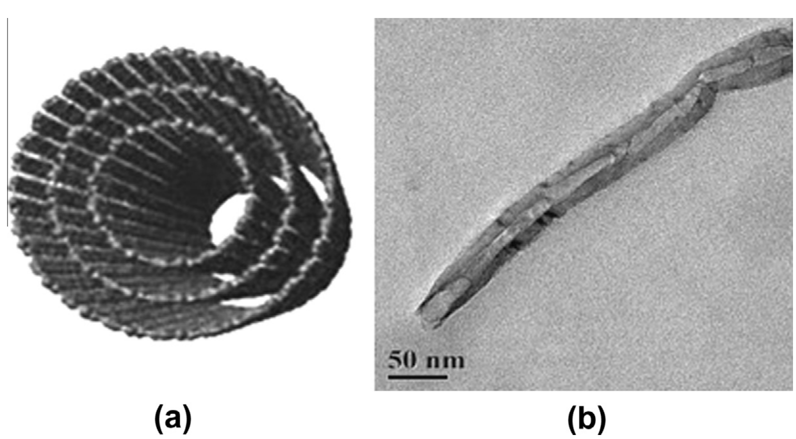

Fig. 1. The structure and morphology of the MWCNTs: (a) computer-generated image; (b) microscopic image.