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Electromagnetic wave absorption properties of helical carbon fibers and expanded glass beads filled cement-based composites

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A B S T R A C T

The cement based composites for electromagnetic (EM) wave absorption were prepared by introducing helical carbon fibers (HCF) and expanded glass beads (EGB), and the influences of HCF mass fraction, EGB volume fraction, and sample thickness on the EM reflection loss were investigated in 2–18 GHz. Results indicate that the EM wave absorption performance increases at first and then decreases with the increase of HCF mass fraction. And the values of absorption peaks and effective bandwidth below −10 dB increase monotonically with the increase of EGB volume fraction. The cement based composites with 2 wt% HCF, 60 vol% EGB, and 20 mm thickness exhibits optimal EM wave absorption performance. The minimum reflection loss can be −17.8 dB and the effective bandwidth for −10 dB reaches 13 GHz. The high EM absorbing capacity and wide effective bandwidth can be attributed to the unique chiral structure of HCF and low permittivity of EGB.

1. Introduction

As the extensive application of household electrical appliances, wireless communication devices, and electronic products, the electromagnetic (EM) pollution of architectural space, which can do harm to public health and cause the information leakage, has become a serious environmental issue [1–3]. EM shielding is one of the most used EM protection methods, however, it cannot thoroughly eliminate EM radiation, and moreover the reflected wave may cause secondary pollution. Therefore, the EM wave absorbing materials, which can transform the EM energy into heat energy or others, are increasingly demanded to improve the EM environment of architectural space.

Cement materials, which possesses high strength, strong corrosion resistance, and excellent durability, is the most commonly used inorganic cementitious materials in construction engineering, however, its EM wave absorption performance is not satisfactory. In general, the EM properties of cement material can be adjusted by introducing dielectric or magnetic loss fillers, and that is a feasible way to improve the EM wave absorption performance of cement materials. The most commonly used dielectric and magnetic loss fillers include carbonaceous materials [4–7], ferrites [8,9], metal powder [10], and industrial by-product [11] etc.. However, excellent EM wave absorption performance cannot be obtained by adding fillers into cement matrix merely, due to the impedance mismatching caused by the compact interior structure of the hydrated cement. In order to adjust the interior structure and improve the EM wave absorption properties of the cement composites containing dielectric or magnetic fillers, porous aggregates with low permittivity and density, such as fly ash [12,13], expanded polystyrene [14,15], expanded perlite [16,17], and hollow glass microspheres [18], are introduced into cement matrix. The relevant research results indicate that the EM wave absorption performance of cement composites can be further improved by the introduction of porous aggregates [12–19].

Expanded glass beads (EGB) are widely used as a kind of filler to produce cement mortar [18,20,21], because it possesses many merits such as light weight, high compressive strength, heat-shielding performance, sound-absorbing performance, and closed pore structure. Helical carbon fiber (HCF) is a kind of novel carbonaceous material, which possesses helical morphology, chirality, high conductivity. And the spring-like HCF shows different interactions against EM waves and stronger EM wave absorption capacity compared to the traditional carbon materials, such as straight-like carbon fiber [22,23], powder-like carbon black [24,25], and plate-like graphene [26–28] et al. The EM wave absorption properties of carbon microcoils (CMC)/polymethyl methacrylate (PMMA) composites was investigated by Motojima et al. [29], and the results indicated that the introduction of CMCs in PMMA composites resulted in strong EM wave absorption, and the lowest reflection loss can be lower than −30 dB. Suda and co-authors [30] fabricated a carbon nanocoils composite, it shows a good absorption property in W band frequencies and a reflection loss of −32 dB can be

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Table 1
Chemical compositions of 42.5 R Portland cement.

Chemical composition	CaO	SiO	Al_2O_3	Fe_2O_3	SO_3	MgO
Content/wt%	62.64	23.85	6.12	3.26	2.32	1.81

achieved at 79.2 GHz. Thus, the HCF has been considered as an ideal EM wave absorbent [29–34]. However, cement based composites filled with HCF for EM wave absorption are rarely reported.

In this study, cement based composites with excellent EM wave absorbing properties was prepared using chiral HCF as absorbent and EGB as porous aggregates, and the EM wave absorption properties of the composites were studied in the frequency range of 2–18 GHz. The effects of HCF mass fraction, EGB volume fraction, and sample thickness on the EM wave absorption effectiveness were discussed in detail.

2. Experimental

2.1. Materials

The cement used in this study was ordinary Type P.O 42.5 R Portland cement, which is produced by Tangshan Quanhe cement Co., Ltd., China, and its chemical compositions are given in Table 1. HCF, with the density of 0.16 g/cm^3, was produced by Guangdong Shuanghong New Material Technology Co., Ltd., China. The EGB, with the average diameters of 1–2 mm, was supplied by Guangdong Longhu Sci. & Tech. Company Ltd., China, and its physical properties are shown in Table 2. Deionized water and high performance dispersing agent (type 4050A, produced by Weifang Winbos New Material Co., Ltd, China.) were needed as well in this study.

2.2. Sample preparation

The dispersing agent was first dissolved in a certain amount (two-thirds of the total amount) of water to obtain the dispersant solution, and then the weighed HCFs were added into the prepared dispersant solutions and dispersed in an ultrasound disperser for 30 min. The dispersing agent/HCF ratio by weight of each sample was selected as 1:5. The prepared dispersed mixture and the remaining water were mixed with cement and EGB in a mortar mixer for 5 min. Afterwards, the prepared mixture was poured into oiled molds with the size of 180 mm × 180 mm × 10/20/30 mm (for reflection loss measurement), 22.9 mm × 10.2 mm × 5 mm and 7.9 mm × 15.8 mm × 5 mm (for EM parameters measurement in X and Ku band, respectively), 40 mm × 40 mm × 160 mm (for mechanical properties measurement) and vibrated to remove air bubbles. The specimens were removed from their molds after 24 h and cured in a moist room for 28 days. The mix proportions of the prepared specimens are listed in Table 3.

2.3. Testing methods

The morphology of HCF, EGB, and prepared cement composites were characterized by scanning electron microscopy (SEM, Quanta 200) and three-dimensional video microscope (KH-7700). The compressive strength and flexural strength of the cement based composites are tested by a flexural and compressive strength testing machine (TYE-300D).

Table 2
Physical properties of EGB.

Colour	Bulk density (g/cm^3)	Compressive strength (N/mm^2)	Softening point (°C)	Particle size (mm)
Milk white	0.23 ± 0.03	1.6	700	1–2

Table 3
Mix proportion and bulk density of specimens.

Sample	EGB (vol.%)	HCF (wt%)	Thickness (mm)	Bulk density (g/cm^3)
1#	0	0	20	1.76
2#	40	0	20	1.23
3#	40	1	20	1.28
4#	40	2	20	1.26
5#	40	3	20	1.15
6#	0	2	20	1.74
7#	20	2	20	1.45
8#	60	2	20	1.01
9#	40	2	10	1.21
10#	40	2	30	1.19

The EM parameters of HCF and EGB were tested by coaxial flange method in the frequency range of 2–18 GHz. The preparation process of the samples for coaxial flange method measurement is as below: the tested materials were mixed with molten paraffin wax (with a 50% volume concentration), then made into toroidal shape with 7 mm outer diameter, 3.04 mm inner diameter, and 3 mm thickness. The EM parameters of the as-prepared cement composites were measured by waveguide method in X-band and Ku-band. Due to the limitation of the test system, the EM parameters cannot be measured in 2–8 GHz by waveguide method. An Agilent N5234A vector network analyzer (VNA), 50 mm coaxial airline, X-band waveguide, Ku-band waveguide were used in the measurement of EM parameters.

EM wave absorption properties were measured using arching reflected method with an Agilent N5234A VNA in the frequency range of 2–18 GHz, and the test system is shown in Fig. 1. The test system should be calibrated before measurement, in order to make sure of the accuracy of the testing results. In addition, the cement composites specimens for EM parameters and EM wave absorption properties measurement should be dried completely, to avoid the test error caused by extra moisture.

3. Results and discussion

3.1. EM parameters of HCF and EGB

The EM parameters of HCF and EGB are measured by coaxial flange method, and the results are presented in Fig. 2 and 3, respectively.

Fig. 2(a) and (b) represents the real part and imaginary part of complex permittivity and permeability of HCF in the frequency range of 2–18 GHz. It can be seen from Fig. 2(a), with the increase of frequency, the real part (ε') of complex permittivity declines from 25 to 8.3, and the imaginary part (ε'') declines from 22.5 to 7.3. The values of dielectric loss factor (tan δ_e) are shown in Fig. 2(a) as well, it can be observed that the tan δ_e fluctuate in the range of 0.85–1.2, which proves that the HCF possesses strong dielectric loss capacity. The real part (ε')

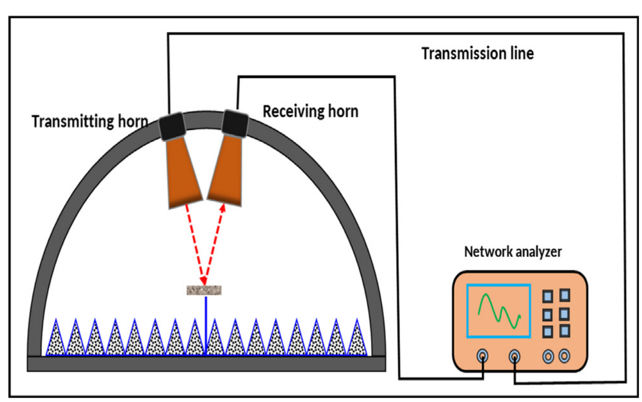

Fig. 1. Sketch map of the arch reflecting method system.