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Electromagnetic wave absorption properties of honeycomb structured plasterboards in S and C bands

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ABSTRACT

This paper provides a feasible way to design honeycomb structured plasterboard for electromagnetic (EM) wave absorption in S and C bands by filling gypsum slurry into carbon black (CB) coated paper honeycomb. The EM wave reflectivity of the prepared plasterboard was investigated by arched testing method, and the influences of CB contents and geometrical parameters of honeycomb structure on the wave absorption were analyzed. The obtained results show that the wave absorption performance of the honeycomb structured plasterboard can be enhanced by increasing the CB content and the honeycomb height, due to the enhancement of dielectric loss capacity and multiple reflections between the honeycomb walls. Moreover, the smaller honeycomb edge length is more conductive to EM wave absorption, because of the increase of the effective permittivity of the honeycomb structured plasterboard. When the edge length and height of honeycomb are 6 mm and 9 mm, respectively, and the CB content is 0.6% in mass, the reflectivity can be less than −10 dB (90% EM wave is absorbed) in the frequency range of 2.5–8 GHz.

1. Introduction

In recent years, electromagnetic (EM) wave in S and C bands is widely used in wireless communication tools, local area networks, personal digital assistant, and other communication equipment. However, the indoor EM pollution, which can lead to the disoperation of precise electronic equipment, the leak of secret information and the threat to human beings health, has occurred along with it [1–4]. To solve EM field pollution problems, broadband and strong absorption EM wave absorber used in constructional engineering are the focus of extensive studies. Plasterboard with the characteristics of light weight, high strength, noise and thermal isolation, and inflaming retarding is one of the most commonly used decorative building materials. But few studies on the EM wave absorbing plasterboard have been reported [5,6].

Nowadays, the EM wave absorbing composite structures which are contemporaneously load bearing and wave absorbing are widely studied. For most of EM wave absorbing composite structures used in construction engineering, such as multiple layer structure [7], sandwich structure [8] and pyramidal structure [9] etc., the problem of large thickness and heavy weight could not be avoided, thus, their application would be limited. Honeycomb structure is widely used because of its high strength-to-weight ratio, which provides low-density support for absorbers. The studies on the honeycomb structure absorbers [10–13] indicate that broadband and strong absorption can be achieved by designing honeycomb structure with thinner thickness. P. Bollen et al. [12] prepared a multifunctional EM wave absorbing sandwich structure material based on a honeycomb core filled with CNT-reinforced polymer foam. Large EM absorption was attained by simultaneously minimizing the reflection and transmission, and high stiffness versus density performance was obtained as well. A lightweight and broadband microwave absorber was designed by Choi et al. [13] using honeycomb structure, the multiple scattering leads to the excellent absorption performance. A specific sample showed excellent broadband-absorbing performance with −10 dB reflection loss from 2 GHz to 14 GHz.

In order to obtain a kind of plasterboard with broadband and excellent EM wave absorbing property, aiming at the prevention of indoor EM radiation in S and C bands, honeycomb structured plasterboard was devised and fabricated by filling gypsum plaster into the open space of the honeycomb structure coated with carbon black (CB). The absorption properties were investigated and the effects of CB concentration and size parameters of honeycomb structure on the EM wave absorption were analyzed as well. The proposed honeycomb structured plasterboard can be a strong candidate for a broadband EM wave absorbing building material.

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2. Experimental

2.1. Raw materials

The gypsum powders were purchased from Shandong Yongsheng Gypsum Powder Plant, China, and the initial setting time and final setting time are 6 and 20 min, respectively. The acetylene carbon black was supplied by Tianjin Jinqiushi Chemical Plant, China. And the main parameters are shown in Table 1. The paper honeycomb plates were procured from Sichuan Litong Composite Material Technology Company, China. The size parameters of the honeycomb used in this study are as follows: the edge length is 6 mm and 8 mm; the height is 5 mm, 7 mm and 9 mm, respectively. Polyvinyl alcohol (PVA), retarder and deionized water were needed as well. The ratio of the retarder to gypsum powders was 0.1% in mass. The EM parameters of gypsum and CB are shown in Fig. 1.

2.2. Fabrication of samples

The processing procedure for fabricating honeycomb structured plasterboard involves 3 steps, and the flow chart is shown in Fig. 2. (1) Preparation of the wave absorbing impregnation liquor. CB and PVA were used as absorbent and binder, respectively. The PVA was mixed with deionized water and stirred for 5 min. And then CB was added into the solution and stirred homogeneously for 1 h. The water/PVA/CB ratio by weight was selected as 24:2:1. (2) Preparation of wave absorbing honeycomb plate. Paper honeycomb plate was dipped into the as-prepared impregnation liquor, and the CB mass fraction was determined by dipping time. After dried at 80 °C for 2 h, the wave absorbing honeycomb plates were obtained. (3) Preparation of honeycomb structured plasterboard. The water and gypsum powders were mixed in a mass ratio of 0.4:1 to obtain gypsum slurry. In order to obtain honeycomb structured plasterboard with a fixed size of $180 \times 180\ mm^2$, the absorbing honeycomb plate, which was cut into $180 \times 180\ mm^2$, was put into a mould with the size of $180 \times 180 \times 10\ mm^3$. Meanwhile, the gypsum plaster was poured into the mould as well, and then smoothed the surface. After 8 h, the sample was removed from the mould, and dried at 60 °C until the weight did not change with time. The thickness of all the prepared plasterboards is 10 mm.

The preparation process of the samples for EM parameters measurement is as below: the tested materials were mixed with molten paraffin wax (with a 80% filler volume concentration), then made into toroidal shape with 7 mm outer diameter, 3.04 mm inner diameter and 3 mm thickness for measurement.

2.3. Testing method

The EM parameters of the toroidal samples were tested by coaxial flange method with an Agilent N5234A vector network analyzer and 7 mm coaxial airline. The EM reflectivity of the honeycomb structured plasterboards was tested by arched testing method in the frequency ranges of 2–8 GHz according to the national standard GJB 2038A-2011. The testing system of arch reflecting method is shown in Fig. 3. The vector network analyzer should be calibrated before the measurement, in order to make sure of the accuracy of the testing results.

3. Results and discussion

3.1. Theoretical analysis

Honeycomb structure can be considered as a periodic structure formed by hexagonal lattice, as shown in Fig. 4(a). The honeycomb structured plasterboard prepared in this paper is a two-phase medium: one is the gypsum filled in the hexagonal vacant cylinders of honeycomb structure, and another is the absorbing medium coated on the honeycomb walls. Based on the Ref. [14,15], the approximate expressions for the effective permittivity of honeycomb structured plasterboard can be summarized as:

Table 1
Main parameters of carbon black.

DBP (ml/100 g)	Resistivity (Ω cm)	Particle size (nm)	Ignition loss	pH	Iodine adsorption number (g/kg)	BET specific surface (m^2/g)
≥ 260	2.0	30–50	≤ 0.3%	6–8	≥ 280	66.5

$$\varepsilon_{\text{eff}} = \varepsilon_a \frac{(2-g)\varepsilon_0 + g\varepsilon_a}{g\varepsilon_0 + (2-g)\varepsilon_a} \tag{1}$$

where $g = 1 - a^2/t^2$ is the fill factor, a and t are the geometrical parameters of honeycomb structure as shown in Fig. 4(b). The ε_0 and ε_a are the permittivity of filling material (gypsum powders) and absorbing medium (carbon black), respectively. It can be observed from Eq. (1) that the effective permittivity of the honeycomb structured plasterboard is closely related to the geometrical parameters of honeycomb structure and the permittivity of filling material and absorbing medium.

For an EM wave absorbing plate, according to the transmission line theory and impedance matching principle, the EM wave reflectivity (R) can be expressed as[16]:

$$R = 20\ \lg\left|\frac{Z_{in} - Z_0}{Z_{in} + Z_0}\right|,\ Z_{in} = \sqrt{\frac{\mu\mu_0}{\varepsilon\varepsilon_0}}\ \tanh\left(j2\pi fd\sqrt{\varepsilon\varepsilon_0\mu\mu_0}\right) \tag{2}$$

where Z_{in} is the input impedance at the air-material interface; $Z_0 = (\mu_0/\varepsilon_0)^{1/2}$ is the characteristic impedance of free space; d is the thickness of an absorbing plate; f is the frequency of incident wave; ε_0 and μ_0 are permittivity and permeability of vacuum, respectively; ε and μ are relative permittivity and permeability of the absorbing plate, respectively.

According to the above analysis, it is evident that the EM wave absorption performance of honeycomb structured plasterboard may be determined by the size (edge length and height) of honeycomb structure and the permittivity of filling material and absorbing material.

3.2. Effect of CB contents on the absorption properties

Fig. 5 presents the EM wave absorption properties of the honeycomb structured plasterboards with different mass fractions of CB coated on the honeycomb walls. It can be observed from Fig. 5 that the wave absorption of the plasterboards increases remarkably with the increase of CB contents in S and C bands, the peak values and effective bandwidth (less than −10 dB) are visually changed as well. For the sample with 0.9% CB in mass, 6 mm honeycomb edge length and 8 mm height of honeycomb, a lowest reflectivity of −24 dB is obtained at 4.5 GHz, and the bandwidth in which the reflectivity is less than −10 dB is 5.2 GHz (2.8–8 GHz). When the edge length and height of honeycomb come to 8 mm and 7 mm, respectively, the wave absorption of the sample with 0.9% CB can be better than −10 dB in the frequency of 3–8 GHz, and the lowest reflectivity of −18.5 dB is obtained at 7.5 GHz.

CB, which is a kind of strong dielectric loss EM wave absorbent, can attenuate the EM wave by tunnel effect, leakage conductance effect, damping vibration, quantum effect, and polarization and