Composite Structures 201 (2018) 608–615

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Design and manufacture of a dual-functional exterior wall structure for 1.1–5 GHz electromagnetic radiation absorption

Shuai Xie[a,b,*], Zhijiang Ji[a], Zhonghe Shui[b], Bin Li[a], Jing Wang[a], Guoyan Hou[a], Jimei Wang[a]

[a] State Key Laboratory of Green Building Materials, China Building Materials Academy, Beijing 100024, PR China
[b] School of Materials Science and Engineering, Wuhan University of Technology, Wuhan 430070, PR China

ARTICLE INFO

Keywords:
Exterior wall structure
Reflection loss
Periodic structure
Multi-layer structure
Electromagnetic absorption

ABSTRACT

In order to solve the increasing serious electromagnetic (EM) radiation pollution, this paper presents a dual-functional exterior wall structure for EM radiation protection. The EM wave absorption properties of the exterior wall structure were investigated in 1.1–5 GHz using arch reflecting method, and results indicate that the optimal absorption property with effective bandwidth below −10 dB reaches 3.7 GHz (1.1–4.8 GHz) can be obtained by the combination of periodic structure and multi-layer structure. The destructive interference, dielectric loss of carbon black (CB), and multiple reflection and scattering of expanded perlites (EP) are the main EM wave absorption mechanisms. The absorption peaks of reflection loss curves are caused by destructive interference, and effective bandwidth is determined by the dielectric loss capacity of CB. Moreover, the multiple reflection and scattering of EP particles play a major role in EM wave absorption. It is expected that the devised exterior wall structure has great potentials in EM radiation protection.

1. Introduction

In recent years, with the expanded applications of electrical and electronic devices in industrial, commercial, and military applications, there is an explosive increase in GHz range electromagnetic (EM) radiation, which can cause a series of problems in EM interference, human health, information safety, environmental pollution, etc. [1–3]. The applications of building materials with the EM wave absorbing properties in engineering construction can make buildings possess EM radiation protection ability. There have been many studies on the EM wave absorbing building materials, including cement based materials [4–6], ceramic materials [7,8], glass matrix materials [9,10], ceilings [11], etc., however, most of the reported building materials exhibit excellent EM wave absorbing properties in high frequency ranges. Thus, it becomes urgent to design and fabricate EM wave absorbing building materials or structures with more effective absorbing performance in lower frequency ranges, especially in 1–5 GHz frequency ranges.

The research results of some multiple layered absorbers indicate that the effective absorption bandwidth can be broadened by the design of multiple layered structure [12–15]. Choi and co-authors [12] developed a triple-layered composite for EM wave absorption, which boasts an outstandingly broad bandwidth of reflection loss (RL) below −10 dB from 4.7 to 13.7 GHz. Optimal RL of the epoxy resin based double-layer composite coatings with carbonyl iron and carbon black (CB) as absorbents can be −17.3 dB at 3.2 GHz [15]. The absorbers embedded with two-dimensional periodic structures show excellent EM wave absorption performance in wide frequency ranges, especially in S and C band [16–20]. In our previous study [17], we prepared an EM wave absorbing gypsum composites by embedding with CB coated fiberglass mesh, the results demonstrate that the prepared gypsum composites can effectively absorb S band EM wave. RL values of hollow-porous carbon fiber composites pasted periodic structures can be lower than −10 dB in the whole C band [18]. Thus, the design of multiple layer structure and periodic structure is beneficial to improve the EM wave absorption performance in lower frequency ranges.

Fig. 1 shows the sketch diagram of a common exterior wall insulation structure, it is obvious that the exterior wall insulation structure is a kind of multiple layer structure, additionally, there is a layer of glassfiber mesh with periodic grids on the surface of insulating layer. Therefore, we are trying to design an improved exterior wall structure based on the multiple layered structure and the periodic structure, realizing the integration of EM wave absorption and thermal insulation functions. And to the best of our knowledge, this kind of exterior wall structure has not been reported.

In this work, we prepared a dielectric loss glassfiber mesh and EM wave absorbing cement mortar using CB as an absorbent, and applying them to the exterior wall structure. The basal layer of the wall was replaced by a thin conducting layer so as to facilitate testing. The effect

* Corresponding author at: State Key Laboratory of Green Building Materials, China Building Materials Academy, Beijing 100024, PR China.
E-mail addresses: xs5649@163.com, xieshuai0822@sina.com (S. Xie), zhshui@whut.edu.cn (Z. Shui).

https://doi.org/10.1016/j.compstruct.2018.06.079
Received 25 December 2017; Received in revised form 13 June 2018; Accepted 21 June 2018
Available online 27 June 2018
0263-8223/

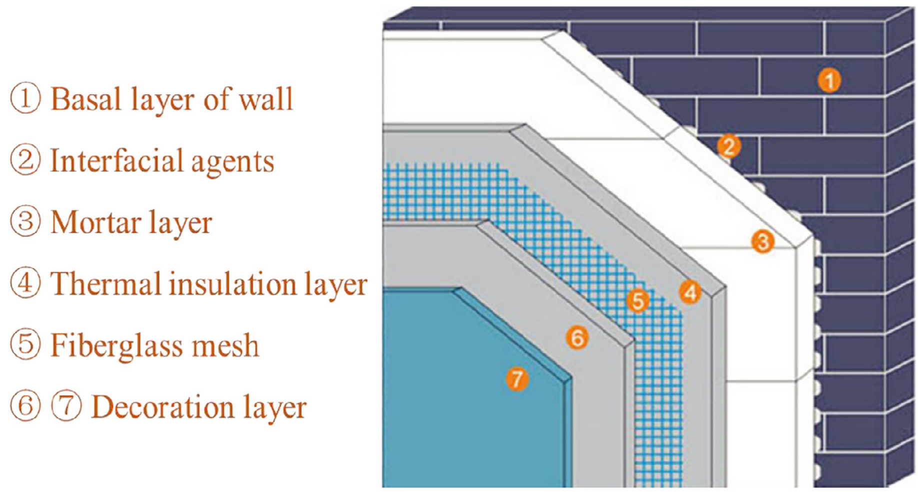

Fig. 1. Sketch diagram of external wall insulation structure of buildings.

of dielectric loss glassfiber mesh, insulating layer thickness, and mortar compositions and thickness on the EM wave absorbing properties in 1.1–5 GHz were investigated. The EM wave attenuation mechanism was discussed as well. The RL of the exterior wall structure designed in this study can be nearly less than −10 dB in the whole testing frequency range.

2. Experimental

2.1. Materials

Fiberglass mesh (ARNP-100L) with 6 mm × 6 mm grid size was purchased from Xiangyang Huierjie Co., Ltd., China. The carbon black (CB), which was used as EM wave absorbent in this study, was produced by Tianjing Jinqiushi Chemical Industrial Co., Ltd., China. Micromorphology of CB particles is shown in Fig. 2. The thermal insulation material was extruded polystyrene (XPS) boards (Suzhou Scott Insulation Materials Co. Ltd., China), and the main properties of XPS boards are listed in Table 1. The cement used was Type P·O 42.5 R Portland cement, which was produced by Tangshan Quanhe Cement Co., Ltd., China, and its chemical composition is shown in Table 2.

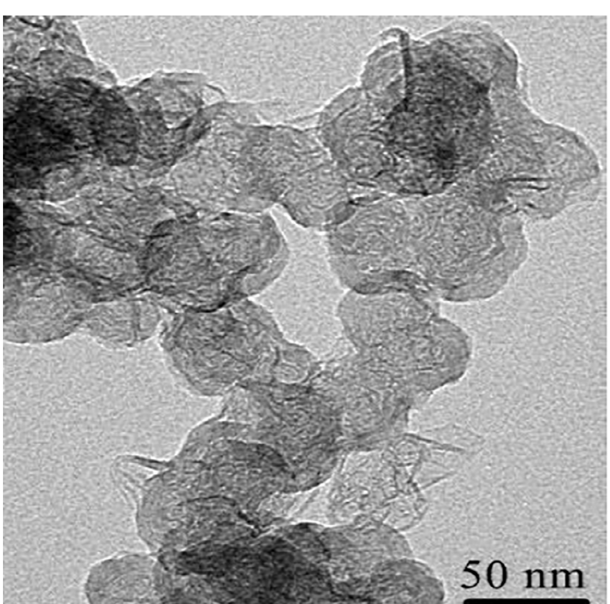

Fig. 2. TEM image of carbon black particles.

Table 1
Main properties of the XPS boards.

Thermal conductivity/ W/m·K	Fireproofing grade	Flexural Strength/ MPa	Compressive strength/MPa	Low temperature bending
0.03	B1	0.25	0.15	≤0.01

Table 2
Chemical composition of the cement.

CaO	SiO	Al_2O_3	Fe_2O_3	SO_3	MgO
62.64	23.85	6.12	3.26	2.32	1.81

Expanded perlite (EP), which were used as wave-transparent aggregates in the mortar layer, were procured from Shanghai LongYuan Industrial Co., Ltd., China. The average diameters of the EP particles is 1 mm, and the bulk density is 150 kg/m^3. The flake graphite, supplied by Qingdao Yanhai Carbon Materials Co., Ltd., China, was used as conductive filler in the conducting layer. Polyvinyl alcohol (PVA, BP17) and pure acrylic emulsion (PAE, BLJ-9806), produced by Chang Chun Group, Taiwan and Shanghai Baolijia Chemical Co., Ltd., China, were used as binding agent, and the main technical index of them are listed in Table 3 and Table 4, respectively. Deionized water with a conductivity of 1.5 μs/cm was prepared by a reverse osmosis pure water system (Arium 61316).

Some auxiliary materials were needed as well, including ash calcium powders (ACP) with a fineness of 400 meshes, coarse whiting powders (CWP) with a fineness of 800 meshes, silica sand (SS) with a fineness of 180 messes, re-dispersible emulsion powder (RDE), hydroxy propyl methyl cellulose (HPMC), and dispersing agent (WinSperse 4050).

2.2. Fabrication method

Two kinds of wall structures were designed as shown in Fig. 3. Fig. 3(a) and (b) represents the sketch map of interference type wall structure and composite type wall structure, respectively. The fabrication process of the specimens involves the following several steps.

2.2.1. Preparation of dielectric loss fiberglass mesh

The wave absorbent CB, adhesive PVA, PAE, and dispersing agent were mixed with deionized water for 60 min to prepare the impregnating solution, and deionized water/PAE/PVA/CB/dispersing agent ratio by weight was selected as 20:10:2:2:1. Then, the fiberglass mesh