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Development of layer structured wave absorbing mineral wool boards for indoor electromagnetic radiation protection

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A B S T R A C T

To prevent and control the severe indoor electromagnetic radiation and obtain a broadband wave absorbing material for constructional engineering, layer structured mineral wool boards with carbon black (CB) absorbent were devised and fabricated, and the reflection loss was studied in the frequency ranges of 2–18 GHz. The morphology, microstructure and electromagnetic characteristics of mineral wool and CB were studied by scanning electron microscopy, transmission electron microscopy and vector network analyzer, respectively. When the single-layer mineral wool board contains 3% CB, the reflection loss is less than −10 dB (90% electromagnetic wave is attenuated) in the frequency ranges of 2–3 and 7–18 GHz. The reflection loss of double-layer mineral wool board is under −10 dB in the whole frequency ranges of 2–18 GHz. The results show that the interior structure of the mineral wool board is benefit to the absorption property, and the design of double-layer structure can further improve the absorbing property.

1. Introduction

With the rapid development of electrical and electronic industry, the electromagnetic pollution, which will do harm to human health and decrease the sensitivity of electronic equipment and even cause severe fault of date or accidents, has become increasingly serious issue in recent years [1–3]. One of the effective ways to prevent or eliminate the electromagnetic radiation is the use of electromagnetic wave (EMW) absorbing materials. Therefore, there have been many studies on the EMW absorbing materials applied in constructional engineering, such as cement based materials [4,5], gypsum based materials [6], ceramic tiles [7], wood based materials [8], etc.

The primary condition for a good EMW absorbing material is impedance matching, which can decrease the reflection of the incident wave on the interface between free spaces and absorbing materials and be in favor of the improvement of absorbing properties. Therefore, substantial methods have been researched to adjust the impedance matching of EMW absorbing building materials, such as adding wave-transparent aggregates to matrix [9,10], designing multi-layer structure [11,12] or any other structures [13,14]. Guan et al. [15] investigated the wave absorbing properties of cement based composites by filling expanded polystyrene (EPS) particles to adjust the impedance matching, of which the reflectivity was less than −8 dB between 8–18 GHz and the bandwidth for −10 dB reaches 6.2 GHz. Zhang et al. [16] studied the absorbing effectiveness of cementitious composites with a three-layer structure, when the thickness is 30 mm, the reflectivity is under −10 dB in the frequency ranges of 8–18 GHz. The experimental results, which have been reported, indicate that the impedance matching of an EMW absorber can be improved by the porous interior structure, and the effective bandwidth can be broadened by the design of multi-layer structure.

Mineral wool is a general term covering a variety of inorganic fibrous materials, such as rock wool, glass wool and slag wool, which is manufactured from natural ore, waste glass and blast-furnace slag, respectively. Mineral wool based plates, a kind of architectural decorative and fitting materials, is typically used in construction projects for heat insulation, cold and fire protection, and noise insulation [17]. The mineral wool based plate is formed by the mineral wool fibers cross each other, and lots of interspaces exist in it, which can provide more transmission path for the incident wave and improve the impedance matching. Carbon black is widely used in the field of EMW absorbing materials and most of the absorbing materials containing CB as absorbing agent possess good absorbing properties [18–20]. So, it can be speculated that the mineral wool board with CB absorbent, which has the porous interior structure, may be possess stronger EMW absorbing capacity, compared with the cement based or gypsum based materials whose microstructure is compact. Until now, however, few studies of the electromagnetic wave absorbing properties of mineral wool

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based materials have been reported.

In this paper, layer structured mineral wool based materials with broadband absorbing properties were devised based on the impedance matching theory and EMW propagation laws. The reflection loss was investigated in the frequency ranges of 2–18 GHz, and the effect of the microstructure and macrostructure on the absorbing properties was discussed. The mineral wool board prepared in this work could be used in construction projects as architectural decorative and fitting materials and prevent the indoor electromagnetic radiation effectively.

2. Experimental

2.1. Raw materials

In this work, granulated mineral wool, produced by Shanghai Yannuo New Building Materials Co., Ltd., China, was used as substrate materials, and the chemical compositions are shown in Table 1. The absorbing agent was acetylene carbon black, which was purchased from Tianjin Jinqiushi Chemical Plant, China. And the main parameters of the acetylene carbon black are shown in Table 2. Some auxiliary materials were also needed in this work, such as modified starch, attapulgite (ATTP), polyacrylamide (PAM). The modified starch and ATTP were used to improve the anti-deformability of mineral wool board, and the role of PAM was flocculating agent. During the preparation of double-layer samples, the epoxy resin was used as binders.

2.2. Sample preparation

The granulated mineral wool, CB, modified starch, ATTP and distilled water were mixed and stirred rapidly for 5 min, then added the PAM, stirring for another 5 min. Then, the mixture was poured into molds with the size of 200 mm × 200 mm, and manually compressed molding after pumping the redundant water by a vacuum pump. Then the samples were removed from their molds and put into a drying oven at 50 °C until the weight did not change with time. The single-layer samples for reflection loss measurements had been prepared. For double-layer samples, two single-layer samples were bonded by a very thin layer of epoxy resin. The composition of each sample is listed in Table 3.

The preparation process of the toroidal shape samples for electromagnetic parameters measurement is as below: the tested materials were dispersed in molten paraffin wax, and the uniform mixture were molded into toroidal shaped samples with the size of φ 7 mm × φ 3.04 mm × 3 mm, the mass fraction of the tested materials in the samples was 80%. The sample for the waveguide method is rectangle, and the sizes are 10.2 mm × 22.9 mm × 10 mm (for X-band) and 7.9 mm × 15.8 mm × 10 mm (for P-band), respectively.

2.3. Testing method

The morphology and microstructure of mineral wool and CB particles were investigated by means of scanning electron microscopy (SEM, Quanta200) and transmission electron microscopy (TEM, Tecnai F20 ST). The electromagnetic parameters of raw materials are measured by coaxial transmission/reflection method at frequency ranges from 2 to 18 GHz, and the electromagnetic parameters of the prepared mineral wool boards are measured by waveguide method at frequency ranges from 8.2 to 18 GHz, an Agilent N5234A Vector Network Analyzer, 7 mm coaxial airline, X-band and P-band waveguide and Agilent 85071E Measurement Software were used.

The microwave absorption properties are tested by the arched testing method, with an Agilent N5234A vector network analyzer, Agilent 85071E Software, and six pairs of horn antennas. The test frequency ranges from 2 to 18 GHz. The vector network analyzer should be calibrated before measurement, in order to make sure of the accuracy of the testing results.

3. Results and discussion

3.1. Morphology characterization of mineral wool and CB particles

The morphology of the mineral wool is revealed by SEM images, as shown in Fig. 1(a). It can be seen that the mineral wool was cylindrical fiber, and the diameter of mineral wool fiber ranges from several micrometers to tens micrometers. The fibrous structure of the mineral wool can form lots of interspaces in the mineral wool based boards. These interspaces can provide more transmission path for incident electromagnetic wave, and decrease

Table 3
Thickness and composition of each sample.

No.	CB content (wt%)		Thickness (mm)	
	Matching layer	Absorbing layer	Matching layer	Absorbing layer
1#	0		10	
2#	1		10	
3#	2		10	
4#	3		10	
5#	4		10	
6#	5		10	
7#	3		5	
8#	3		20	
9#	1	3	10	10
10#	1	4	10	10
11#	1	5	10	10
12#	2	4	10	10
13#	3	4	10	10

Table 1
Chemical compositions of mineral wool.

Component	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O
Content range (%)	40–52	8–13	1.5–2.7	5.5–6.5	0.1–0.3	10–12	8–15	0.8–2.3	0.8–2

Table 2
Main parameters of carbon black.

DBP (ml/100 g)	Resistivity (Ω cm)	Particle size (nm)	Ignition loss	Ash content	PH	Iodine adsorption number (g/kg)	BET specific surface (m^2/g)
≥ 260	2.0	30–50	≤ 0.3%	≤ 0.2%	6–8	≥ 280	66.5