



Study on EM-parameters and EM-wave absorption properties of materials with bio-flaky particles added



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ABSTRACT

Bio-flaky particles, fabricated through deposition of carbonyl iron on the surface of disk shaped diatomite, demonstrated beneficial performance on electromagnetic parameters. This paper will detail the improvements to the electromagnetic parameters and absorbing properties of traditional absorbing material generated by the addition of bio-flaky particles. Composites' electromagnetic parameters were measured using the transmission method. Calculated test results confirmed with bio-flaky particles were added, composites' permittivity increased due to the high permeability of bio-flaky particles. Secondly, the permeability of composites increased as a result of the increased volume content of iron particles. Composites with bio-flaky particles added exhibited superlative absorption properties at 0.5 mm thickness, with a maximum reflection loss of approximately -5.1 dB at 14.4 GHz.

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1. Introduction

Electromagnetic wave (EM-wave) equipment employing gigahertz (GHz) frequency ranges has been widely used in both civil and military applications such as personal digital assistants, wireless communication tools, radar, etc. [1,2] However, ensuing radiation hazards, electromagnetic interference (EMI) and electromagnetic compatibility (EMC) problems have gradually become more prevalent and alarming. One way to alleviate this issue is the development of thinner, more portable and multiband complex communication products. The preparation of thinner and broader-band absorbing materials may provide an effective method for overcoming the loss of dielectric and magnetic properties. According to theoretical studies, the material's EM-wave absorption performance is determined by electromagnetic parameters (EM-parameters): permittivity and permeability [3,4]. The traditional materials, carbonyl iron particles (CIPs), are absorbents and have been widely used in absorbing composites due to their large values of magnetic saturation and Snoke's limit at high frequency [5]. By changing the shape of carbonyl iron particles, their permittivity and permeability are improved [6,7]. Particles with a flaky shape have larger

permittivity and permeability than spherical particles [6]. The resonance frequency of absorbing materials decreases and the maximum reflection loss (RL) can be increased [6]. Conversely, some study results showed with the addition of high dielectric constant materials, the EM-parameters and mixture structure are changed significantly. Also the EM-wave absorption performance of materials is improved.

The bio-magnetic particles not only have complex morphology, shape and multi-level sub-structure, but also have special EM-properties [7–9]. A thin iron layer of bio-flaky particles was coated with chemical vapor deposition, using disk shaped diatom as a template. These particles showed good EM-parameter performance (high complex permittivity and high complex permeability) as well as microwave absorbing abilities [9]. The pores of the diatom are maintained by core-shell particles, allowing for low density material classification. When the particles are mixed with rubber, it creates a net to be laid across diatom pores, increasing the strength of the composite. This paper focuses on the preparation of thin and high performing microwave absorption composites with bio-flaky particles added at 2–18 GHz frequency. The uniform distribution of the composites filled with bio-flaky particles and flaky carbonyl iron particles (FCIPs) was confirmed. Electromagnetic parameters including complex permittivity and complex permeability were compared and analyzed. Finally, the RL of composites was calculated at variable thicknesses.

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2. Experiment

2.1. Materials

The implemented matrix for this experiment included Methyl Vinyl Silicone Rubber and 2, 5-dimethyl hexane as vulcanized agent, supplied by LaiZhou Jintai Silicon Industry Co. Ltd., China. The filler included the raw commercial absorbents FCIPs and bio-absorbents. The CIPs (3 μm) and FCIPs were supplied by Shenyang Hangda Technology Co. Ltd., China, and the bio-flaky particles were prepared through a bio-limited forming method. Lastly, iron atoms were deposited on the diatomite surface through thermal decomposition [9]. The average diameter of FCIPs was 5 μm and the thickness was approximately 0.5 μm , while the average diameter of bio-flaky particles was approximately 40 μm . Bio-flaky particles exhibited an average aspect ratio of 15. The micro-structure of the two particles is displayed in Fig. 1.

2.2. Sample preparation

The absorbing materials were made by mixing the absorbents and silicone rubber in a two-roll mixer for 15–30 min. The bio-flaky particles were then added to the silicone rubber to guaranty their dispersion without aggregation. Finally, vulcanized assistants and FCIPs were added to the compounds. The samples for measuring EM-parameters were modeled to a toroidal shape with outer diameter 7.0 mm, inner diameter 3.04 mm and thickness 2 mm. Mixture proportion for each toroidal shape sample is shown in Table 1. All the compounds were vulcanized at 180 $^{\circ}\text{C}$ for 5 min.

2.3. Testing

The morphology of each absorbent and the sample cross-section was observed using a scanning electron microscope (SEM CamScan CS3400). The EM-parameters of the absorbing composites were measured using the transmission method with an AV3627 vector network analyzer and a coaxial cable in the frequency range from 2 to 18 GHz. The calculated RL was determined according to the following equations [8]:

$$RL = 20 \log \left| \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \right| \quad (1)$$

$$Z_{in} = Z_0 \sqrt{\frac{\mu_r}{\epsilon_r}} \tanh \left\{ j \frac{2\pi f d}{c} \sqrt{\mu_r \epsilon_r} \right\} \quad (2)$$

Table 1
The mixture proportion of each sample.

NO.	Carbonyl iron powder (vol %)	FCIPs (vol %)	Bio-flaky particles (vol %)	Density ρ (g/cm ³)
1	40	0	0	3.72
2	0	40	0	3.70
3	0	38	2	3.65
4	0	35	5	3.59
5	0	30	10	3.51

where Z_{in} is the normalized input impedance of the microwave absorbing materials and $Z_0 = \sqrt{\mu_0/\epsilon_0} = 120\pi\Omega$ is the intrinsic impedance of free space. ϵ_r and μ_r are complex permittivity and permeability constants for absorbing material, while ϵ_0 and μ_0 complex permittivity and permeability constants of free space, respectively. Finally, f is the frequency of microwaves, and d is the thickness of the absorbing materials.

3. Results and discussion

3.1. Density and dispersion of absorbents in composites

With the help of a forming mold, standard toroidal shape samples were fabricated and the volume of the samples was determined (62.4 mm³). After weighing the samples, the corresponding densities were calculated. The bio-flaky particles were comprised of two layers: iron coating as the outer layer and diatomite as the inner layer. Specifically, amorphous silica structured diatomite belongs to a family of lightweight materials. This would cause the density of bio-flaky particles to be lower than the density of the pure carbonyl iron particles. Table 1 showed the density of different samples with different proportions of absorbents added by calculation. It was clear through the results in the table, as the volume of bio-flaky particles increased, the composite density decreased.

The non-uniform dispersion and agglomeration of the absorbents dramatically influenced the EM-parameters of the composites, resulting from the minimal space occupied by the toroidal samples [9]. Therefore, the uniform dispersion of absorbents in the composites must first be verified. SEM images of the composites were taken in order to properly observe the samples' morphology and microstructure. The morphology of the absorbing composites filled with CIPs and bio-flaky particles was displayed in Fig. 2a, and a detailed image of the dispersion state between FCIPs and bio-flaky particles was shown in Fig. 2b. The images clearly show the bio-flaky particles were dispersed in the absorbing composites

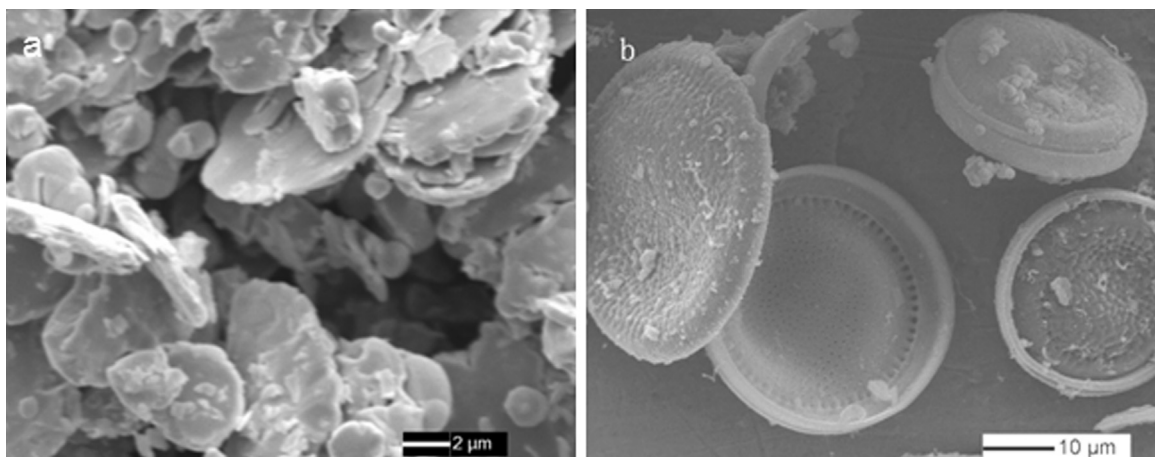


Fig. 1. SEM images of the absorbents, (a) FCIPs, and (b) bio-flaky particles.

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