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# A new absorbing foam concrete: preparation and microwave absorbing properties

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**Abstract.** The foam concrete was fabricated by adding the foaming agent which composite ordinary Portland cement with plant and animal protein into cement paste, and the electromagnetic wave absorption properties were studied for the first time as well. The studies showed that the electromagnetic waves can be absorbed by multiple reflections and scattering within the porous material. Thickness and filling ratio have a great influence on the electromagnetic wave absorbing properties in 2-18 GHz of the foam concrete, the greater the thickness, the better the performance of absorption; filling ratio was about 52 vol.%, the absorbing properties achieved the best.

**Keywords:** foam concrete; microwave absorbing; filling ratio; thickness

## 1. Introduction

With the rapid development of electronic information technology, the electromagnetic radiation has become one of the main pollution sources of human life. Diffuse electromagnetic radiation not only do harm to communications, transportation, the accuracy of the electronic equipment and information security, but also endanger people's health (Du *et al*. 2006, Liu *et al*. 2005 and Li *et al*. 2013). Therefore, research and development of microwave absorbing materials with high performance become one of the most important issues. The resources of cementitious materials are abundant, which is the most popular building materials in use today, it is of great significance to develop the cement material with absorbing function for shielding electromagnetic radiation. Currently, the research of cement-based absorbing materials mainly focuses on the addition of absorbents (Nam *et al*. 2012, Li *et al*. 2012, Hutagalung *et al*. 2012 and Guoxuan *et al*. 2011) and fiber material (Chung *et al*. 2000, Wen *et al*. 2004 and Fu *et al*. 1997). Dai *et al.* fabricate carbon black (CB) cement-based composites(CBCC) by adding 2.5% of nano carbon black into cement, which has a peak value of -20.30 dB in frequency 8-26.5 GHz, while the bandwidth in which the reflection loss <-10 dB distributes in the range of 14.9-26.5 GHz (Dai *et al*. 2010). Moreover, Dai *et al.* research the absorbing properties of cement-based composites with steel slag in 1-18 GHz,

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which has a peak value of -12 dB in 13-18 GHz, and the bandwidth < -8 dB is close to 5 GHz (Dai *et al*. 2009). Shen *et al.* (2010) study the absorbing performance of cement-based composites with carbon fiber, which can be found the peak value of RL reaches -27.0 dB at 15.8 GHz, the absorption bandwidth (RL< -10 dB) is 4.4 GHz. However, from the perspective of preparation and absorbing properties of above mentioned materials, the absorbing cement have the disadvantages of high cost, large density, cumbersome process and poor performance, no matter adding absorbents or fiber material. Therefore, the absorbing properties of the cement-based porous materials attract people's attention, Guan et al. (Guan *et al*. 2006, Li *et al*. 2011, Guan *et al*. 2007, Guan *et al*. 2007, Du *et al*. 2006 and Oh *et al*. 2004) add expanded polystyrene (EPS) into cement paste to fabricate porous lightweight cement composite absorbing material, the results show that EPS filled cement composite can significantly improve the electromagnetic wave absorption properties of cement materials, but for the complexity of preparation process, especially in lightweight porous media, it is difficult to be added into the cement matrix uniformly, which have great influence on the absorbing performance.

In view of the above research status, in this paper, the foam concrete was fabricated by adding foam into cement paste matrix by using cement foaming agent to prepare foam. Meanwhile, the electromagnetic wave absorption properties and related mechanisms of foam concrete are studied for the first time.

## 2. Experimental

### *2.1 Sample preparation*

The cementitious starting material used in this study was Portland cement of Type P.O 42.5 R and was produced by Dalian-Onoda Cement Co., Ltd, China. And Animal and plant protein composite cement foaming agent of Type SY-F30 was produced by Yantai Shiyong Construction Machinery Co. Ltd. The physical and chemical characteristics of cement are shown in Tables 1 and 2.

In accordance with the water-cement ratio 0.4 to prepare cement paste, using foaming agent with solution preparation of 1:10 dilution ratio to fabricate foam in the foam generator (compress air to foam), a certain amount of foam were added into cement paste, to prepare foam concrete with different density levels after stirring. Pouring the mixture into oiled moulds with a size of 200×200 mm with the thickness of 10, 20 and 30 mm, meanwhile, a size of 200×200×200 mm, respectively. The specimens were cured for 24 h before demolding with the mean temperature and humidity of 20±2℃ and 95% RH, respectively, and then cured for 28 days. Dry the foam concrete in the drying oven with 50±5℃ to constant weight before performance measurements, the flat specimens were used for testing absorbing properties, and the cube one was tested mechanical properties and porous morphology.

### *2.2 Testing methods*

The electromagnetic absorbing effectiveness of wave absorbing material was denoted with the reflectivity R, which was expressed as $R = 20\log|E_r / E_i|$ (dB), where $E_r$ and $E_i$ referred to the electric field strength of the incident and reflective electromagnetic wave, respectively. The arched test method was used in this study. The set-up was connected to a Hewlett-Packard (HP)

8720B microwave network analyzer with a dynamic standard attenuation of 95 dB.

In order to eliminate the influence of free water which exists in the cement composites on the wave absorbing property, all the samples should be heated in a lower temperature before testing. Mechanics performance test refer to *foam concrete* (JG/T 266-2011), and the porous morphology can be obtained by optical digital microscope, using Image - Pro plus software to analyse statistics, the pores under 10 microns were ignored.

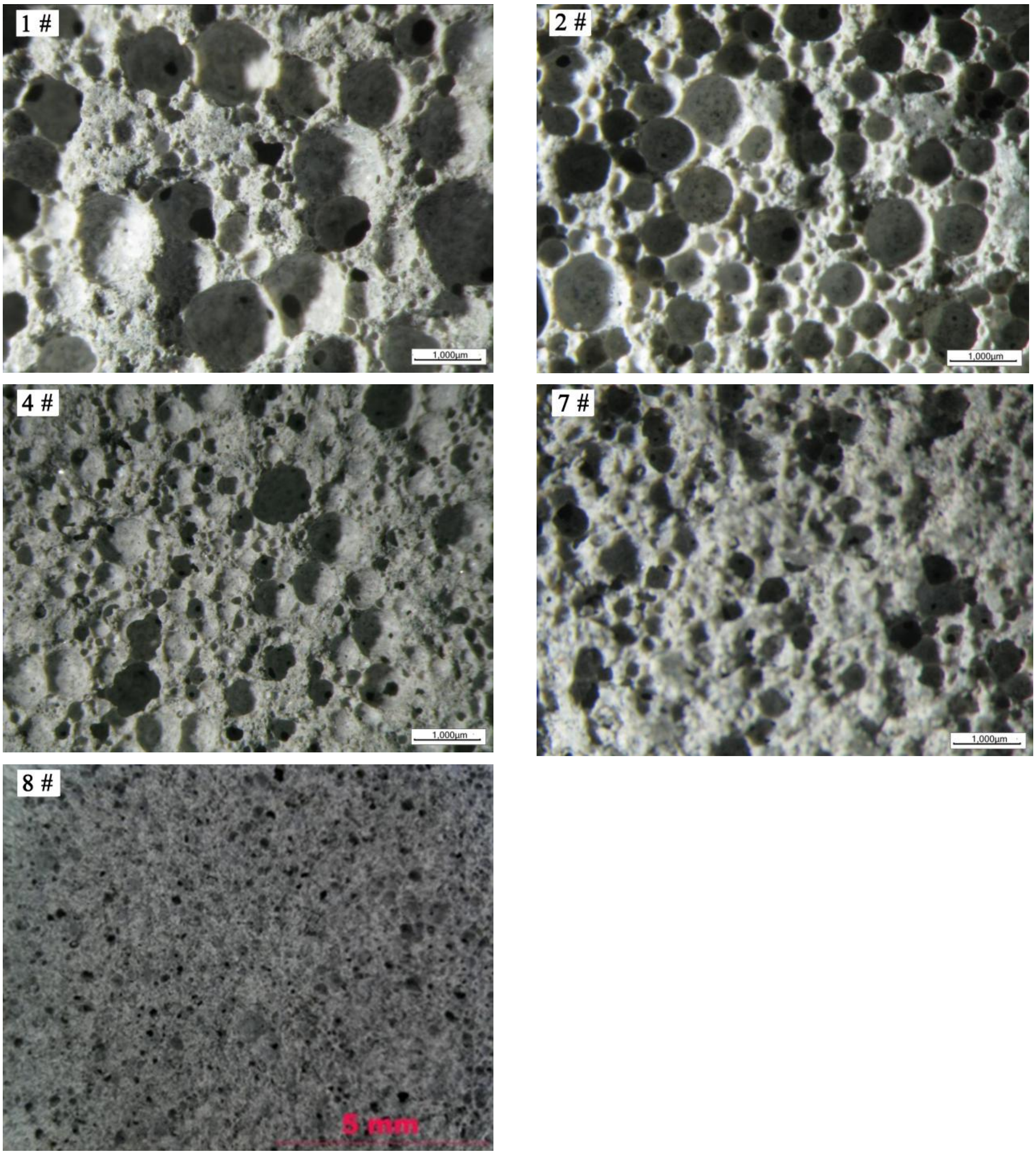


Fig. 1 Fracture surface pore distribution of foam concrete

Table 1 Physical characteristics of cement

| Physical properties | | | | | |
|---|---|---|---|---|---|
| Specific gravity ( $g/cm^3$ ) | Surface area ($m^2/g$) | Flexural strength (Mpa) | | Compressive strength (Mpa) | |
| | | 3d | 28d | 3d | 28d |
| 3.09 | 419 | 6.3 | 9.7 | 29.2 | 50.9 |

Table 2 Chemical characteristics of cement

| Chemical composition (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CaO | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $K_2O$ | $TiO_2$ | $SO_3$ | MgO | $Na_2O$ |
| 57.0 | 5.3 | 24.9 | 3.6 | 1.2 | 0.5 | 3.7 | 3.0 | 0.3 |

## 3. Results and discussion

### *3.1 Influence of filling ratio*

The morphologies of foam concrete with three different filling ratios are shown in Fig. 1. It can be seen that the pore distribution were relatively uniform. Fig. 2 shows the microwave absorption properties of foam concrete with different filling ratios. The reflection loss of foam concrete is mainly better than -5dB in frequency 2-18GHz. The sample 1# with 62.4 vol.% has three obvious peak values of -28.2 dB at 6.2 GHz, -21.1 dB at 10.8 GHz, -18.8 dB at 15.9 GHz, respectively. And the bandwidth < -10 dB reaches 7.9 GHz from the absorbing curve. The sample 2 with 57.8 vol.% has two peak values of -33.1 dB at 5.6 GHz, -24.7 dB at 9.4 GHz, respectively, and the bandwidth < -10 dB achieves 8.7 GHz. When the filling ratio is 52.1 vol.% (sample 4), it has one obvious peak value of -20.6 dB at 5.5 GHz, and the bandwidth in which the reflection loss <-10 dB reaches as high as 10.7 GHz. Continuously, sample 7 with 46.7 vol.% also has a peak value as high as -34.9 dB at the frequency 10 GHz, but its bandwidth <-10 dB is only 6.6 GHz. The peak value of sample 8 (filling ratio is 42.3 vol.%) reaches -26.8 dB at 4.9 GHz, and the bandwidth of -10 dB is 7.5 GHz. It is clear that that the peak values shift towards the lower frequency as the filling ratio decreases from 62.4 vol.% to 42.3 vol.%. With the increase of foam concrete porosity, allowing more electromagnetic waves to enter the foam concrete, and scattering loss increase. However, with the further reduction of density of concrete and the increase of filling ratio, leading to the increase of transmissive wave and the degradation of wave absorption performance. Results show that filling ratio is 52.1 vol.%, the absorbing properties achieved the best which bandwidth <-10 dB achieve 10.7 GHz in the range of 2-18 GHz.

### *3.2 Influence of sample thickness*

Fig. 3 indicates the effect of thickness on wave reflection loss. As is shown in Fig. 3, the sample 3 with thickness of 10 mm has one obvious peak value of -11.4 dB at 12 GHz. And the bandwidth < -10 dB is only 0.5 GHz in the whole frequency range of 2-18 GHz. The sample 4 with thickness of 20 mm has one peak value of -20.6 dB at 5.5 GHz, and the bandwidth < -10 dB achieve 10.7 GHz. Similarly, the peak value of sample 5 with thickness of 30 mm reaches -17.2 dB at 3.37 GHz, and the bandwidth of -10 dB is 13.5 GHz. And when the thickness is 40 mm (sample 6), there is no obvious peak value, the bandwidth in which the reflection loss < -10 dB achieves as high as 15 GHz. Thickness of sample has a great influence on the electromagnetic wave absorption: the thicker the thickness of concrete, the better wave absorption properties are for foam concrete in the range of 10-40 mm. This is because the thickness of foam concrete increase which also leads to the increase of the reflection and multiple scattering between the pores, resulted in the improvement of absorbing properties, ultimately. It has a difference with literature (Oh *et al*. 2004), which results show the input impedance of material change with the increase of thickness, when thickness reaches a certain value, the absorbing properties of materials will have a downward trend. But it can not be seen a similar trend in the foam concrete.

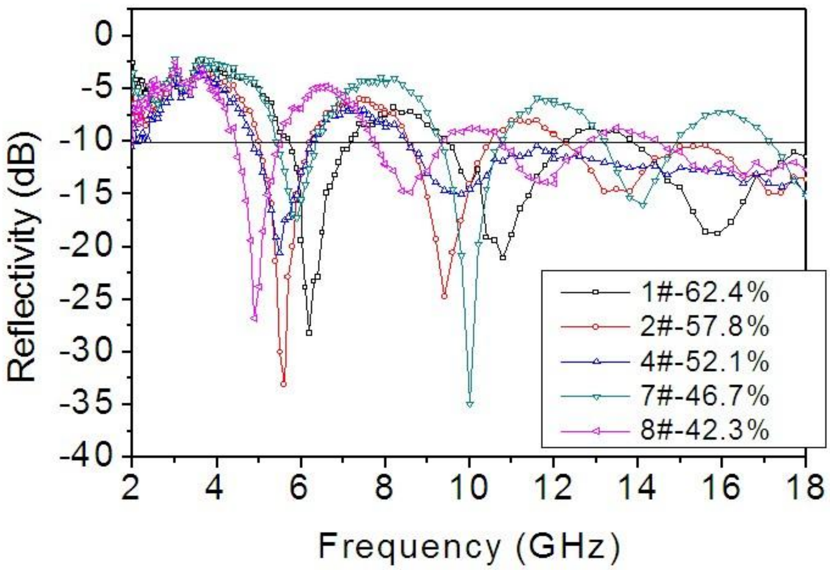


Fig. 2 Effect of porosity on microwave reflectivity

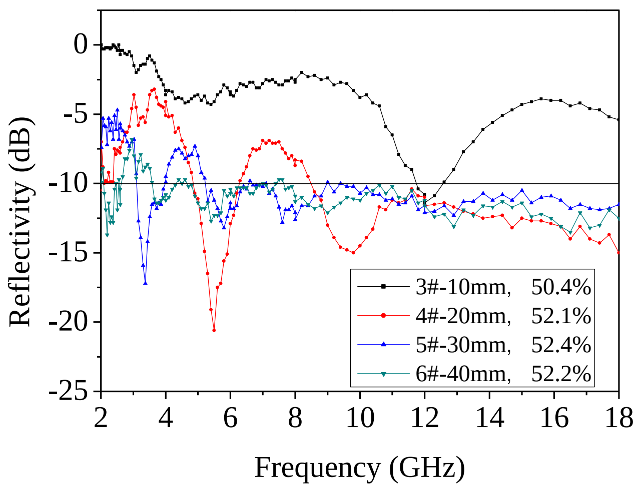


Fig. 3 Effect of thickness on microwave reflectivity

### *3.3 Theory analysis*

Cement matrix is slightly conductive and has the ability of microwave absorption, the attenuation of electromagnetic wave by cement paste can be mostly attributed to the dielectric and magnetic loss of the metal oxide components and some minerals in the cement components (Cao *et al*. 2004). On another hand, due to a certain of porosity inside cement, when the incident wave transmits into the material, it will be reflected and scattered by the walls of the holes, a part of electromagnetic waves will be consumed by converting electrical energy into heat. But plain cement has a uniform and relatively compact structure, which causes an impedance mismatching and inhibits the incident wave transmission into the material. However, the introduction of closed pores into the foam concrete, which porous diameters are roughly between 0.01 mm and 1 mm, improves the impedance matching between the material and free space, which makes the incident wave easier to transmit into the material and attenuated by the absorption medium. The lossy mechanisms of EM waves inside foam concrete are extremely complicated. As is shown in Fig. 4, the multiple reflections and scattering loss of single porosity, the multiple scattering between the pores inside the concrete must be taken into consideration.

According to literature (Duan *et al*. 2006), the attenuation of the incident wave can be expressed approximately as

$$I(\mathrm{x}) = I_0 \exp(-\mathrm{n}\frac{k^4|\chi|^2}{6\pi}\cdot x) \tag{1}$$

where $I_0$ and $I(\mathrm{x})$ are the energy intensity at the material surface x =0 and through a thickness x in the material. $k = 2\pi \mathrm{f}\sqrt{\varepsilon_0\mu_0\varepsilon\mu}$ is the wave number in absorption medium, $\frac{k^4|\chi|^2}{6\pi} = \sigma_{SC}$ is scattering cross section, $n$ denotes the number of pore in a unit volume of foam concrete, and $\chi$ means polarizability.

For a single-layer plate absorber, its reflection loss with respect to a normally incident plane wave can be expressed as

$$R = 20\lg\left|\frac{Z-1}{Z+1}\right| \tag{2}$$

$$Z = \frac{Z_{in}}{Z_0} = \sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh(\mathrm{j}\frac{2\pi d}{\lambda_0}\cdot\sqrt{\mu_r\varepsilon_r}) \tag{3}$$

in which $Z$ is the input impedance normalized by $Z_0$, $d$ is the thickness of the material and $\lambda_0$ is the wavelength of the incident wave in free space.

From Eqs. (1)-(3), it is evidently shown that the wave attenuation has a direct relationship with the porous scattering cross section, filling ratio and thickness of the material.

### *3.4 Mechanics property analysis*

Foam concrete proportions as well as the strength and density are shown in Table 3. It can be seen from Fig. 4, the compressive strength of foam concrete decreases roughly linearly as the porosity increases. When the filling ratio is 62.4 vol.%, it is tested a minimum compressive strength for 5.3 MPa; when the filling ratio is 42.3 vol.%, the compressive strength achieves the highest 15.7 MPa.

Table 3 Test result and foam concrete proportions of samples

| Sample No. | Mix design | | | Dry apparent density /(kg·m$^{-3}$) | pore rate/(%) | Compressive strength/MPa | Thickness of sample/mm |
|---|---|---|---|---|---|---|---|
| | Mass of cement/kg | Mass of water/kg | Volume of foam/L | | | | |
| 1 | 750 | 338 | 1450 | 714 | 62.4 | 5.3 | 20 |
| 2 | 750 | 338 | 1200 | 802 | 57.8 | 7.4 | 20 |
| 3 | 750 | 338 | 950 | 943 | 50.4 | 10.4 | 10 |
| 4 | 750 | 338 | 950 | 911 | 52.1 | 9.8 | 20 |
| 5 | 750 | 338 | 950 | 905 | 52.4 | 9.6 | 30 |
| 6 | 750 | 338 | 950 | 909 | 52.2 | 9.6 | 40 |
| 7 | 750 | 338 | 700 | 1012 | 46.7 | 14.2 | 20 |
| 8 | 750 | 338 | 550 | 1096 | 42.3 | 15.7 | 20 |

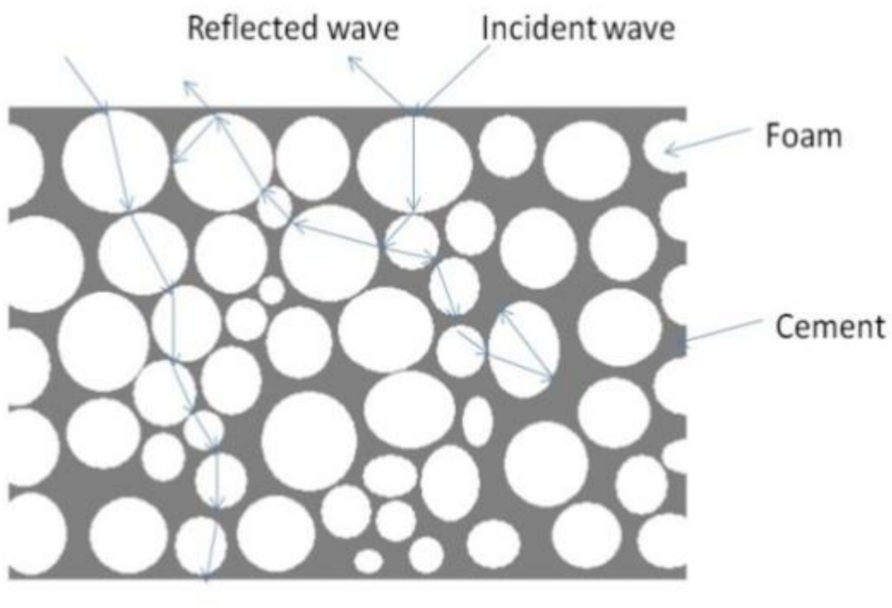


Fig. 4 The sketch map of transmission of incident wave in foam concrete

## 4. Conclusions

Foam concrete has good absorbing properties, which has a direct relationship with the filling ratio and thickness of foam concrete. When the filling ratio is 52.1 vol.% with the thickness of 20 mm, the bandwidth in which the reflection loss < -10 dB is as high as 10.7 GHz which achieve the best absorbing performance. Moreover, the sample with 46.7 vol.% has a peak value as high as -34.9 dB at the frequency 10 GHz. The characteristics of foam concrete presents that the thicker the thickness of sample, the better absorbing properties are. When the thickness is 40 mm with the filling ratio of about 52 vol.%, which bandwidth < -10 dB achieve 15 GHz in the range of 2-18 GHz.

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