Journal of Applied Mathematics and Physics, 2014, 2, 843-847
Published Online August 2014 in SciRes. http://www.scirp.org/journal/jamp
http://dx.doi.org/10.4236/jamp.2014.29094

Influence of Silica Fume on the Reflectivity and Transmission Efficiency of Cement-Based Materials

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Received 28 May 2014

Abstract

As a kind of mineral admixture, silica fume has low permittivity, which will affect the electromagnetic properties of cement-based materials. To study the effect of silica fume on the properties of cement-based materials, the reflectivity, transmission efficiency and pore structure were analyzed by using the vector network analyzer and mercury injection apparatus. Results show that silica fume can make the mortar more compact and the porosity of sample with 9% silica fume is only 17.8%, which is far lower than the control sample; With the increase of the silica fume content, the peak of reflectivity curve increases from −23.2 dB to −16.0 dB, and then decreases from −16.04 dB to −28.7 dB in the frequency range of 6 – 18 GHz. Reflectivity of sample with 3% content of silica fume is lower than other samples within 26.5 - 40 GHz; Transmission efficiency of samples shows the trend of increase with silica fume content increases from 0% to 6% within 8.2 - 12.4 GHz, 12 - 18 GHz and 26.5 - 40 GHz, but when the content increases from 6% to 9%, the transmission efficiency of samples reduces.

Keywords

Silica Fume, Cement-Based Materials, Reflectivity, Transmission Efficiency

1. Introduction

The development of radar technology makes many military facilities easy to be found and destroyed. Stealth performance of military facilities built by using building materials with the performance of low reflectivity or high transmission efficiency can be improved.

Silica fume is a by-product in the process of melting metallic silicon or ferrosilicon alloys. Silica fume particles are very fine; most of particles size is less than 1 μm, and the average particles size is about 0.1 μm, which is 1/100 of the cement particles diameter [1] [2]. Silica fume has been widely used in the production of cement concrete, especially high strength concrete (HSC) and high performance concrete (HPC). Because of pozzolanic

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How to cite this paper: Zhang, X.Z., Zhang, G.D., Zhang, Y. and Zhou, Z.H. (2014) Influence of Silica Fume on the Reflectivity and Transmission Efficiency of Cement-Based Materials. *Journal of Applied Mathematics and Physics*, **2**, 843-847.
http://dx.doi.org/10.4236/jamp.2014.29094

reaction and high fineness, silica fume can make cement-based materials denser and improve their mechanical property and durability [3].

On the other hand, silica fume containing a lot of the amorphous silica owns low permittivity and loss tangent values. Therefore, compared with cement, silica fume has more excellent wave-transparent performance. So it can be used to adjust electromagnetic properties of cement based materials [4]. Tan [5] found that electromagnetic shielding of cement based materials was increased after adding silica fume. Zhang [6] used silica fume to improve impedance matching between cement based absorbing materials and free space. Compared with the single-layer structure, the reflectivity of the double-layer decreased by 6 - 8 dB. Although above-mentioned researches referred to applications of silica fume in cement-based shielding and absorbing materials, influence of silica fume on the reflectivity and transmission efficiency of cement-based materials has not been studied. So cement based materials mixed with silica fume was prepared, and their properties were tested and analyzed combined with its micro structure in this study.

2. Experimental Programs

2.1. Raw Materials

In this study, P.O 42.5 with 7.3 MPa flexural strength and 46.2 MPa compressive strength at 28 d was used. Its chemical compositions are shown in **Table 1**. Chemical compositions of silica fume with 0.2 μm average particles size and 25,000 m^2/kg specific surface areas are shown in **Table 1**. In addition, polycarboxylate superplasticizer produced by Shandong Academy of Building Research and standard sand produced by China ISO Standard Sand Co., LTD. was also used in this study.

2.2. Sample Preparation

The cementitious materials/sand/water ratio by weight of mortar was selected as 1:3:0.5, and superplastiser was used by cement mass 1.0%. Firstly, the water and polycarboxylate superplasticizer were poured into a mixer, and then cement and silica fume were added. The mixture was slowly stirred for one minute, followed by rapid stirring for 30 s before sand was added. After resting for 90 s, the mixture was rapidly stirred for another 60 s. After completing the mixing, mortar was poured into models and vibrated to remove bubbles. The size of the specimens is 180 mm × 180 mm × 10 mm. Then samples were put into standard curing box and specimens were removed from their models 24 h later. Samples were cured for 28 days at 20˚C ± 2˚C and 95% relative humidity.

2.3. Test Method

PNA E8363B vector network analyzer produced by Agilent Technologies was used to test reflectivity of specimens by using the method of RCS (Radar Cross-Section). The measurement was carried out in the frequency ranges of 6 - 18 GHz and 26.5 - 40 GHz; the measurement of transmission efficiency was carried out in the frequency ranges of 8 - 12.4 GHz, 12.4 - 18 GHz and 26.5 - 40 GHz; PM60GT-18 mercury intrusion porosimeter produced by QUANTATECH was used to test pore structure.

3. Results and Discussion

3.1. Effect of Silica Fume on the Pore Structure

Figure 1 shows the pore size distribution of specimens with different content of silica fume.

In **Figure 1(a)**, pore size distribution of ordinary mortar is mainly less than 0.1 μm and pore size distribution of ordinary mortar greater than 0.1 μm is almost zero. In **Figures 3(b)-(d)**, except for specimens with 6% content of silica fume, pore smaller than 0.1 μm of other specimens reduces significantly after adding silica fume. It

Table 1. Chemical compositions (%).

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	P_2O_5	MnO	SrO
Cement	22.89	6.98	3.11	55.64	4.51	2.21	0.61	0.27	0.41	0.15	0.29	0.034
Silica fume	96.62	0.21	0.06	1.26	0.40	0.17	0.84	0.21	/	0.14	0.01	0.01

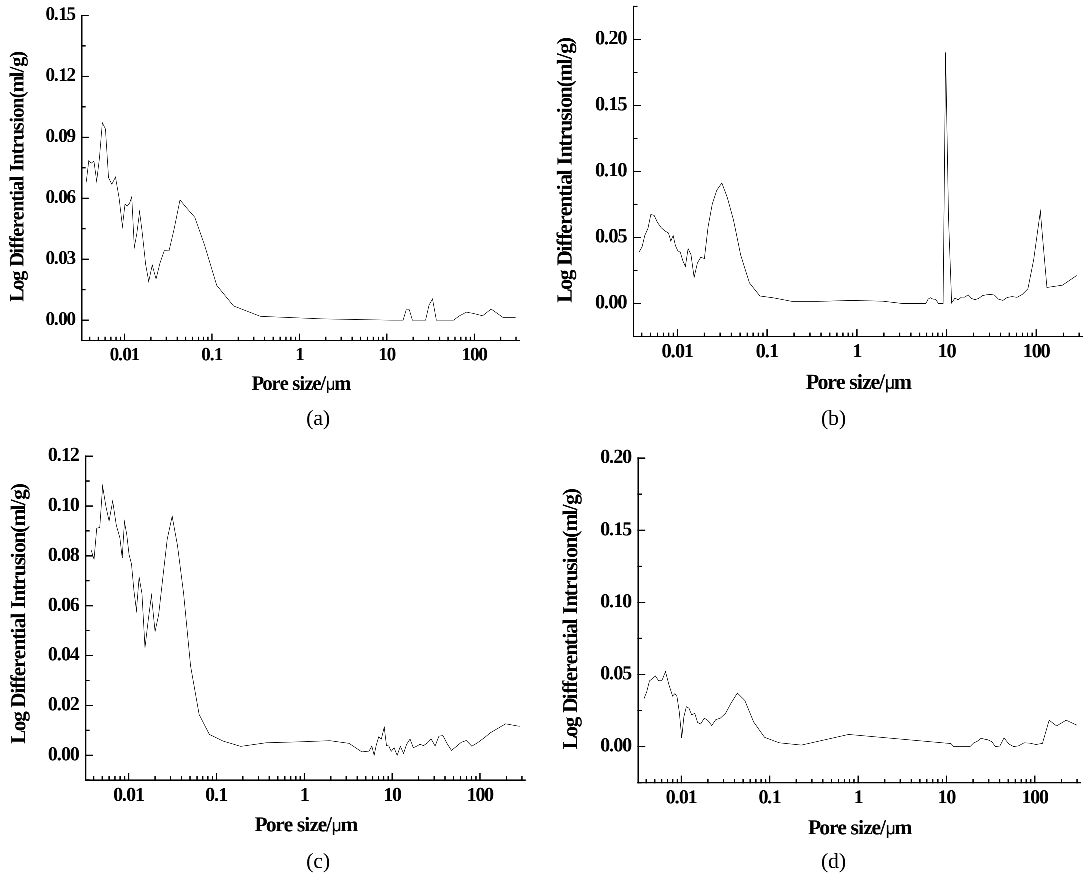

Figure 1. Effect of silica fume on pore size distribution. (a) Specimens with 0% content of silica fume; (b) Specimens with 3% content of silica fume; (c) Specimens with 6% content of silica fume; (d) Specimens with 9% content of silica fume.

illustrates that silica fume can make mortar denser, and this is inappropriate for the spread of electromagnetic wave inside the material and results in the decrease of transmission efficiency.

Tables 2 shows the results of pore structure of specimens with different content of silica fume.

From **Table 2**, porosity of specimens decreases with the increase of silica fume content. Therefore, adding silica fume can reduce the permittivity of mortar by its low permittivity, on the other hand silica fume can also increase permittivity of mortar by reducing the porosity. When the former is the main influence factor, permittivity of mortar will decrease. When the latter is the main influence factor, permittivity of mortar will increase and it is bad for improving the impedance matching.

3.2. Effect of Silica Fume on the Reflectivity

Figure 2 shows reflectivity of specimens with different content of silica fume in the frequency range of 6 - 18 GHz and 26.5 - 40 GHz.

It can be observed from **Figure 2(a)** that reflectivity of each specimen shows a peak at 8 GHz in the frequency range of 6 - 18 GHz and this is due to the interference caused by reflecting of electromagnetic wave from the surface and bottom of specimens. In addition, with the increase of silica fume, the peak shifts from −23.2 dB to −16.0 dB and then to −28.7 dB. From 3.1, it is known that adding low content of silica fume will increase permittivity of mortar and it's bad for improving impedance matching. So, reflectivity of specimens shows different variation trend with the increase of silica fume.

In **Figure 2(b)**, reflectivity of specimens is obviously different from each other. Except for specimens with 3% silica fume, reflectivity of other specimens decreases with the increase of silica fume. It illustrates that silica fume can improve the reflectivity of cement based materials effectively.

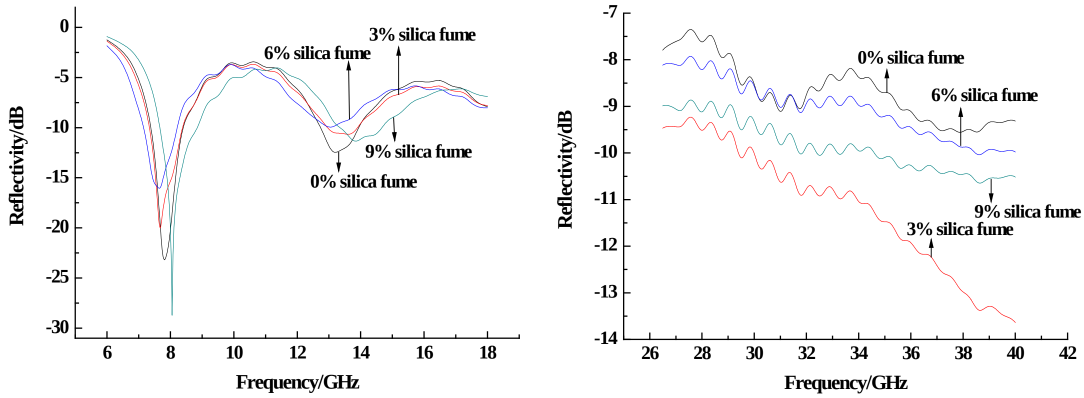

Figure 2. Effect of silica fume on reflectivity. (a) 6 - 18 GHz; (b) 26.5 - 40 GHz.

Table 2. Measuring results of pore structure of mortar.

Content/%	Porosity/%	Mean/nm	Mode/nm	Median/nm	Permittivity/8 - 12.4 GHz	Permittivity/12.4 - 18 GHz
0	22.09	14.20	3.90	35.85	4.3	4.0
3	20.06	16.13	5.12	30.86	4.6	4.1
6	23.56	11.76	3.76	17.40	4.9	4.1
9	17.78	20.88	4.40	646.4	4.5	3.9

3.3. Effect of Silica Fume on the Transmission Efficiency

Figure 3 shows the transmission efficiency of specimens with different content of silica fume in the frequency range of 8.2 - 12.4 GHz, 12 - 18 GHz and 26.5 - 40 GHz.

In **Figure 3**, transmission efficiency of specimens decreases with the increase of frequency in three ranges. Transmission efficiency of control group decreases from 29.3% to 2.3% when the frequency increases from 8.2 GHz to 40 GHz. After adding silica fume, transmission efficiency of specimens decreases firstly and then increases with the increase of silica fume content, but it is less than control group. When silica fume content increases from 0% to 6%, transmission efficiency of specimens decreases with the increase of dosage. But when silica fume content increases from 6% to 9%, the trend is the opposite. This is mainly because adding low content of silica fume makes permittivity of mortar increase and the reflectivity also increases. So transmission efficiency is reduced. When the content increases to 9%, decrease of permittivity improves impedance matching and transmission efficiency increases.

4. Conclusions

1) After adding silica fume, porosity is reduced and this makes permittivity of mortar increase when the content of silica fume is low. Permittivities of mortar with 6% silica fume are 4.9 within 8.2 - 12.4 GHz and 4.1 within 12.4 - 18 GHz and it is bad for improving the reflectivity and transmission efficiency of specimens.

2) With the increase of silica fume, peak of reflectivity curve firstly increases and then decreases in 6 - 18 GHz, but reflectivity decreases in the frequency range of 26.5 - 40 GHz.

3) Transmission efficiency of specimens decreases along with the increase of frequency. But with the increase of silica fume, transmission efficiency increases firstly and then decreases in 8.2 - 12.4 GHz, 12 - 18 GHz and 26.5 - 40 GHz. Transmission efficiency of specimens with 3% silica fume is the best, but lower than control group.

Acknowledgements

This work was sponsored by the National Natural Science Foundation of China (Grant No. 51208227),

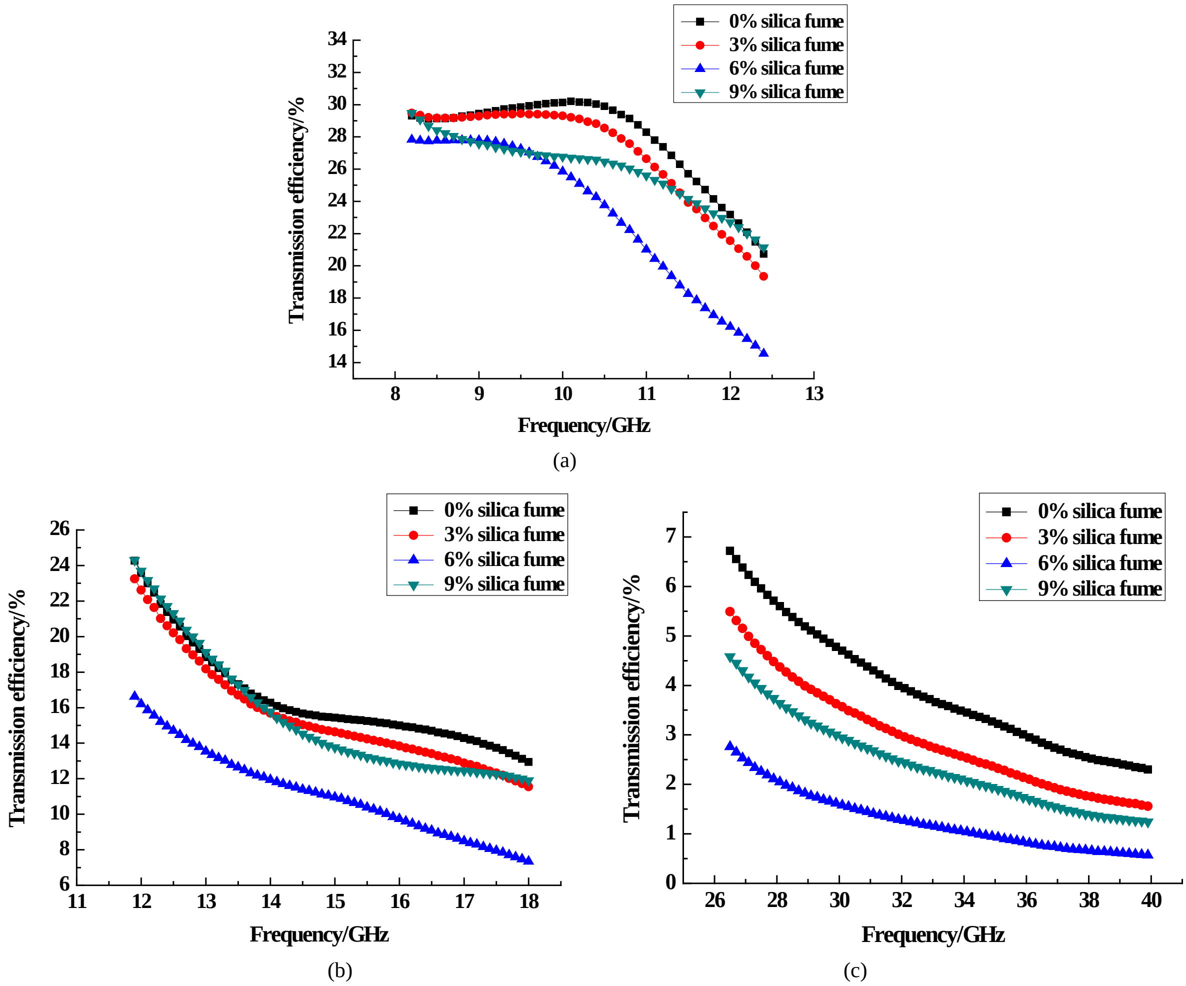

Figure 3. Effect of silica fume on transmission efficiency. (a) 8 - 12.4 GHz; (b) 12.4 - 18 GHz; (c) 26.5 - 40 GHz.

Shandong provincial government for science research (ZR2012EEQ003), Jinan Science & Technology Bureau (201303078) and program for scientific research innovation team in colleges and universities of Shandong province.

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