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Incorporation of sand-based breathing bricks with foamed concrete and humidity control materials

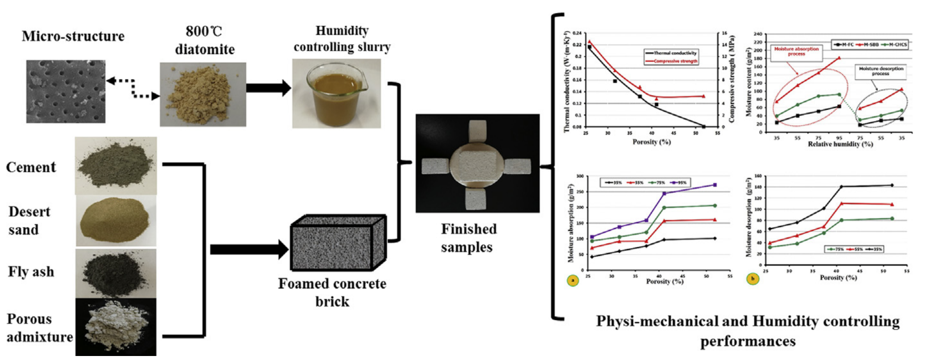
Xuezheng Wang [a], Wenyuan Gao [a,*], Shuang Yan [a,*], Meihong Niu [b,*], Guishan Liu [a], Hongshun Hao [a]

[a] *School of Textile and Material Engineering, Dalian Polytechnic University, Dalian 116034, China*
[b] *School of Light Industry and Chemical Engineering, Dalian Polytechnic University, Dalian 116034, China*

HIGHLIGHTS

- Accurate porous parameters of foamed concrete were characterized and quantified.
- Successful curve simulation between the porous parameters and physi-mechanical properties of SBB.
- A novel Porous systems composing of foamed concrete and HCMs enhances the humidity controlling performance of SBB.
- SBB expanded the practical application of foamed concrete.

GRAPHICAL ABSTRACT



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ABSTRACT

Foamed concrete with five densities were prepared without sintering, then compounded with the humidity controlling slurry to prepare the sand-based breathing bricks (SBB). The accurate porous parameters of foamed concrete were characterized and quantified by Image-pro Plus 6.0 and Matlab 2015a. The effect of these porous parameters on the properties of the SBB were investigated. The optimal physical, mechanical and humidity controlling properties of SBB were achieved with FCa9 of foamed Concrete. The suitable dry density was 910 kg/m^3 with higher compressive strength of 5.25 MPa, thermal conductivity was 0.08 $W{\cdot}(m{\cdot}K)^{-1}$, the max moisture absorption was 272.51 g/m^2 and max moisture desorption was 143.09 g/m^2, which can be used as a wall material for partitioning space to improve indoor air quality.

1. Introduction

Foamed concrete was known as lightweight concrete. Owing to the porous structure, it has the advantages of high porosity, low density, noise isolation, energy absorption, blast mitigation etc. [1–4]. Therefore, foamed concrete is much favored and used by the construction industry. In recent years, the porous structure of foamed concrete has the following applications: Bose et al. [5] experimental results showed that the noise reduction coefficient of cement matrix porous material was increased by 100%, with 40% volume fraction addition of cenospheres. Zhang et al. [6] exhibited the geopolymer foamed concrete acoustic absorption coefficients of 0.7–1.0 at 40–150 Hz. Zhao et al. [7] mixed the polystyrene foam into the cement-based foamed concrete, effectively relieving the dynamic response of the load caused by explosion, with obvious energy absorption and damping effect. Although the above studies had expanded the practical application of

* Corresponding authors at: No. 1 Qinggongyuan, Ganjingzi District, Dalian 116034, China.
E-mail addresses: dlgwy64@163.com (W. Gao), yanye150@outlook.com (S. Yan), nmh414@163.com (M. Niu).

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foamed concrete, there was little research on the combination of foamed concrete and humidity control materials (HCMs).

HCMs can adsorb or release moisture automatically without any power source or mechanical equipment due to its sensitivity to the variations of ambient relative humidity (RH) [8]. Indoor pollution is becoming a serious problem due to the use of decoration materials which usually contains volatile gases such as formaldehyde, benzene, xylene and other Total Volatile Organic Compounds harmful gases [9]. A porous system (Including both macroscopic and microscopic pores) which could both regulate humidity balance and absorb harmful gases would be a superior material to improve indoor air quality. However, there is little research in this area so far.

Foamed concrete is a high porosity material. Nambiar et al. [10] and Liu et al. [11] used the rheometer, scanning electron microscope, vacuum water saturator instrument and image analysis software to analyze the porous parameters of foamed concrete. Ye [12] established the relationship between pore structure and permeability through numerical simulation; Yang et al. [13] identified a good linear correlation between porosity and diffusion coefficient of concrete; Han et al. [14] found that the microstructure of concrete was important for predicting the durability and transport properties of concrete; Akthar et al. [2] explored that the high porosity of the foamed concrete is excellent in thermal conductivity, but poor in compressive strength. The thermal conductivity is a function of the pore structure and the dry density in foamed concrete, and the porous structure has a great influence on the thermal conductivity [15,16].

The above discussions show that the porous structure of foamed concrete has a significant effect on its performance. To study the effect of porous parameters on the performance of sand-based breathing bricks (SBB), five densities of foamed concrete containing the desert sand were prepared. Then, humidity controlling slurry was prepared with humidity control materials. SBB was made by compounding humidity controlling slurry and foamed concrete. Finally, the relation between the porous parameters and the physi-mechanical properties were analyzed, and the effect of these parameters on the humidity controlling performance of SBB were discussed.

2. Experiment

2.1. Materials

The cement (P·O 42.5 R) was provided by Dalian small Noda Cement Co., Ltd, Dalian City, Liaoning Province, China. Desert sand was obtained from Zhangwu County, Liaoning Province, China. The particle size D10 is 37 μm, D50 is 125 μm and D90 is 253 μm after remove particle size greater than 830 μm. The fly ash was supplied by a power plant lay in Linjiang City, China. Porous admixture (Third grade raw diatomite) and Diatomite (sintering at 800 °C, D10 = 6.04 μm, D50 = 22.75 μm, D90 = 49.15 μm) were supplied by a company located in Linjiang City, China.

The foamed agent (H_2O_2) (ω = 30%, AR, Tianjin Kemiou Chemical Reagent Co., Ltd, China) and the water reducing agent (Dalian Sika Building Materials Co., Ltd. China) were purchased in the market. The foam stabilizer ($C_{36}H_{70}CaO_4$, CP) and Polyethylene Glycol 400 (PEG-400, $HO(CH_2CH_2O)_nH$, AR) were obtained from Tianjin Guangfu Fine Chemical Research Institute, Tianjin City, China. Polyacrylamide (PAM, C_3H_5NO, AR, Shandong West Asia Chemical Industry Co., Ltd, China) were bought as the dispersant. Polyvinyl alcohol (PVA, $(CH_2CHOH)_n$) was purchased in the market (AR, Sinopharm Chemical Reagent Co., Ltd, Beijing City, China). The plant oil (corn) was used as defoamer (Which was used to prevent the production of bubbles during ball milling of the HCMs).

2.2. Preparation of SBB

The preparation of SBB was consisted of three parts: the preparation of foamed concrete, the preparation of humidity controlling slurry and the composite of SBB.

2.2.1. Preparation of foamed concrete

Five kinds of mixtures were prepared and the design dry density was set up to be 800, 900, 1000, 1100 and 1200 kg/m^3, marked as FCa8, FCa9, FCa10, FCa11 and FCa12, respectively, which present dry density of foamed concrete is 800, 900, 1000, 1100 and 1200 kg/m^3. To achieve these design dry densities, the various raw material ratios, w/c ratios and additives of these mixes were determined, by trials, ensuring the stability of the wet foamed concrete mix and also that the measured density nearly equal to the design dry density [10,17]. The fly ash was carried out by planetary ball mill (QM-ISP4, Nanjing University Instrument Factory, Jiangsu Province, China), the mass ratio of fly ash and iron ball was set to be 2:3 and the bill speed was set up as 25 r/min for 2 h (Dry grinding, iron cans). The granularity greater than 180 μm were removed after ball milling. The fly ash, desert sand, cement, porous admixture and foam stabilizer were weighted and mixed. The detail properties of each sample was shown in Table 1. Next, the water reducing agent and water were added to the mixture and the mixture was stirred at a rate of 35 r/min for 120 s to generate a homogeneous paste. Then, foamed agent was put in the paste and stirred at the same speed for 90 s to produce a foamed mortar. Finally, the foamed mortar was injected into a mold (100 × 100 × 100 mm) and statically cured (During curing, the foamed concrete in the mold only need to static in the indoor air without other operations) for 24 h. The foamed concrete was cured under standard conditions (20 ± 2 °C, RH >95%) for 28 d after demolding, then the preparation of foamed concrete was accomplished. Microscopic images of foamed concrete surfaces are shown in Fig. 1 by optical digital microscope (KH-8700, Shanghai Spectrum Qian Optical Instrument Co., Ltd., China).

2.2.2. Preparation of humidity controlling slurry

In order to stabilize the HCMs suspended in water, we did a lot of experiments about the humidity controlling slurry before this paper, and obtained the optimal experimental process as follows:

Ceramic balls: 800 °C diatomite: Deionized water: PEG-400: Plant oil mass ratio were set to be 150:20:80:1:1. The ball mill speed was set up as 30 r/min for 30 min (wet grinding, ceramic cans) by planetary ball mill (QM-ISP4, Nanjing University Instrument Factory) to generate a mixed slurry. Then, the slurry was passed through 180 μm sieves (i.e., 100 meshes) to purify and refine slurry. Meanwhile, PAM and PVA were used to configure a solution with a mass fraction of 8% and 6%. Next, PAM and PVA solution were added to the slurry in an amount of 5% and 10%. Finally, the compound slurry stirred at a rate of 30 r/min for 3 h, and the humidity controlling slurry was completed.

2.2.3. Composite of SBB

The irregular part of the foamed concrete was cut off after curing for 28 d. The remaining part was vertically cut into pieces of 20 × 100 × 100 mm. Then, the foamed concrete pieces were immersed into the humidity controlling slurry, meanwhile the slurry was maintained at a rate of 20 r/min rotation. After the foamed concrete were immersed in humidity control slurry for 12 h, taken it out and placed it in a dry box (DHG-9003, Shanghai Xi Wei Science Instrument Co., Ltd.) for drying (80 ± 2 °C for 6–8 h). After that, the complete SBB were prepared.

2.3. Characterization and measurements

2.3.1. Physical and mechanical properties

The dry density (ρg) and compressive strength (P) tests of sample complied with the Chinese Foamed Concrete standard (JG/T266-2011) [18].

$$\rho g = m/(a \cdot b \cdot c) \tag{1.1}$$

$$P = F/(a \cdot b) \tag{1.2}$$

where m is the quality of the sample (kg), ρg is the dry density of the sample (kg/m^3), F is the maximum pressure of the sample can withstand (N), a, b, and c are the length, width and height of the sample (mm). Each set of data is measured three times and averaged.

The porosity (V_k) of the specimen was measured by referring to [19]:

$$V_k = (1 - \rho g/\rho t) \times 100\% \tag{1.3}$$

Table 1
Mix proportions of raw materials.

	Mixes				
	FCa8	FCa9	FCa10	FCa11	FCa12
Design dry density (kg/m^3)	800	900	1000	1100	1200
Cement (kg/m^3)	280	379	368	338	336
Fly ash (kg/m^3)	175	189	147	101	168
Desert sand (kg/m^3)	280	152	221	270	224
Porous admixture (kg/m^3)	14	30	15	41	22
W/C ratio	0.46	0.49	0.46	0.55	0.49
Water (kg/m^3)	211	279	237	246	250
Foamed agent (kg/m^3)	30	26.25	18.75	15	7.5
Water reducing agent (kg/m^3)	1.75	1.25	3.25	1.75	1.25
Foam stabilizer (kg/m^3)	2.75	1.25	2.25	1.75	2.25