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Effects of foaming agent type on the workability, drying shrinkage, frost resistance and pore distribution of foamed concrete

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HIGHLIGHTS

- Three kinds of foaming agents are used to prepare foamed concrete.
- The stability and strength of the foam produced by foaming agents were tested.
- The performance of foamed concrete were characterized.
- A close correlation was found between foaming agent and performance of specimens.

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ABSTRACT

Aiming to explore the effects of the foaming agent type on the properties of foamed concrete, synthetic surfactants (SS), plant surfactants (PS) and animal glue/blood based surfactants (AS) were used to produce foamed concrete with a density of 600 kg/m^3. At this density, the structure and properties of foamed concrete were greatly influenced by the foaming agent type. The FTIR results show that the functional groups of SS, PS and AS are similar. However, the stability and strength of the foam made by SS are much higher than that of AS and PS, which may be due to the higher density and viscosity of SS foam. The experimental results exhibited that the compressive strength of foamed concrete with SS is 11% and 43% higher than that of foamed concrete with AS and PS, respectively. The drying shrinkage of foamed concrete with SS is 13% and 21% lower than that of foamed concrete with AS and PS, respectively. The pore structure of foamed concrete was tested with X-CT and Hardened Concrete Bubble Analyzer. Foamed concrete with SS showed narrower pore size distributions and fewer connected pores compared with the other two, which accounted for the high compressive strength, low drying shrinkage and strong frost resistance of foamed concrete with SS.

1. Introduction

Lightweight materials with high thermal insulation has increasingly become a target of the modern construction and building industry. Foamed concrete is classified as lightweight concrete, in which air-voids are produced in cement paste by suitable foaming agents [1–3]. In some foamed concrete with high density (about 1000 kg/m^3), fine aggregates such as sand [4], recycled glass fines [5], surface-modified tire crumb [6], etc. are also incorporated, which can improve the strength of foamed concrete.

Foamed concrete possesses excellent properties such as low density (from 300 kg/m^3 to 1600 kg/m^3) which helps to reduce the structural dead loads [7–9] and produce high fire resistance [10], low thermal conductivity and good sound insulation [11–13]. In practice, foamed concrete is widely applied in insulated wall panels, ground insulation and bridge packing (filler between arch and bridge deck in arch bridge) [14]. However, foamed concrete also shows some disadvantages, such as low strength, high drying shrinkage and water absorption [15,16], etc., which greatly limit its industrial application.

The performance of foamed concrete produced with different foaming agents varies greatly, because it is related to the stability of the foam which may be damaged by drainage, coalescence and Ostwald ripening (disproportionation) [17]. The current widely used foaming agents are mainly synthetic surfactants (SS), plant surfactants (PS) and animal glue/blood based surfactants (AS). SS usually consists of surfactants and stabilizers [18]. Both PS and AS

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mainly contain proteinaceous substances which are extracted from triterpenoid saponin and animal blood gum, respectively [19].

So far, there are many published researches on foaming agents and foamed concrete. Falliano D et al. [20,21] revealed that the type of foaming agent has a significant impact on the compressive strength of foamed concrete with a dry density between 350 kg/m^3 and 850 kg/m^3, and the type also causes a change in the thermal resistance and sorption coefficient of cellular concrete with a density ranging from 1600 kg/m^3 to 2300 kg/m^3 [22]. Wei She et al. [18] found that with the increasing incorporation of nano-silica particles in foaming agents, the stability of foam is improved. Ameer A et al. [23,24] investigated that the foam performance can significantly affect the pore structure of foamed concrete. Kearsley EP et al. [25,26] verified that there is a close relationship between the pore structure (especially pore diameter and continuity) of foamed concrete and the properties of foamed concrete such as strength, water absorption and drying shrinkage. In addition, Ailar Hajimohammadi et al. [27] found that the homogeneity of pore distribution inside the foamed concrete also affects the performance of the foamed concrete, and the specimens with high homogeneity of pore distribution possess high strength. The pores in the foamed concrete are introduced by foaming agent, and therefore the pore structure and the homogeneity of pore distribution are significantly influenced by the foaming agent type. However, there has been little research on the impacts of different foaming agent type on the performance of foamed concrete so far.

In this investigation, three types of foaming agents, i.e. PS, AS and SS, were utilized to prepare foamed concrete. There are numerous types of synthetic foaming agents, and the SS used in this study mainly contains surfactant (sodium dodecyl sulfate or sodium dodecylbenzene sulfonate), and nanoparticles with diameters less than 50 nm. The dry density of the foamed concrete was 600 kg/m^3. At such a low density, the foam performance plays an important role in the properties of foamed concrete. The structures of the three kinds of foaming agents were characterized by FTIR. The stability and strength of the foam produced by PS, AS and SS were compared. The paste fluidity, water absorption, drying shrinkage, compressive strength and frost resistance of the foamed concrete were tested. The pore structure and pore size distribution of hardened foamed concrete were examined to account for the different performance of the foamed concrete.

2. Materials and methods

2.1. Materials

Chinese 52.5 P·II type Portland cement with a specific surface area of 362 m^2/kg and density of 3160 kg/m^3 was used in this study. The chemical compositions of the cement were determined by X-ray fluorescence (XRF) and presented in Table 1.

SS (produced by Yifa Building Materials Technology Co., Ltd., Jurong, Jiangsu, China), PS (produced by Yousuo Foaming Agent Co., Ltd., Qingdao, China) and AS (produced by Zhonghua Foaming Agent Co., Ltd., Hangzhou, China) were used as foaming agent separately to produce foamed concrete. The FTIR spectra of SS, PS and AS foaming agent is shown in Fig. 1. It can be seen that all the foaming agents exhibit similar peaks of —OH— at 3400 cm^{-1} and —CH at 2900 cm^{-1}, but the peaks of —C=C— at 1600 cm^{-1} only present in AS and PS [28].

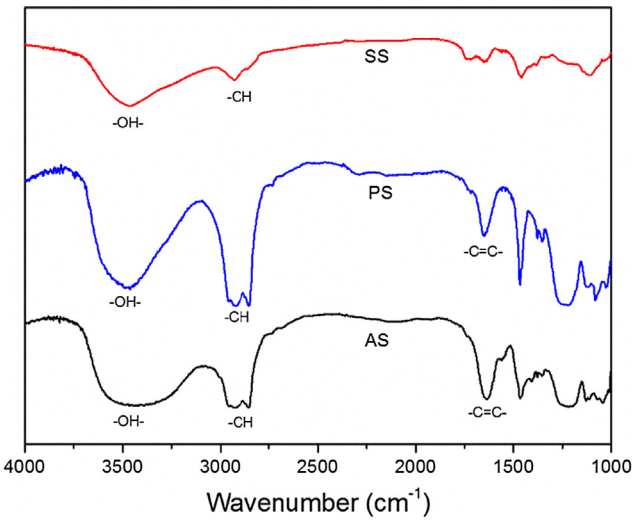

Fig. 1. FTIR spectra of SS, PS and AS.

The foaming agent need to be mixed with water to form a foaming liquid before use. The mixing ratio of each foaming agent to water is provided by the manufacturer. Then the foaming liquid was added to the foaming machine to prepare the foam. To calculate the foam density, the foam was added to a 1 L measuring cup and weighed. The foam density is shown in Table 2. It can be seen that the SS foam has much higher foam density than the other two, due to the higher water content caused by a lower foaming ratio of the SS foam.

2.2. Mix proportions of foamed concrete

At present, the mixing proportion of foamed concrete is mostly calculated according to its target density, because it can be adjusted according to the designed density of foamed concrete and the performance of foam. The mix proportion design method (of 1 m^3 foamed concrete) used in the study is described as follows [29]:

$$\rho_d = S_a m_c \tag{1}$$

$$V_2 = K(V - V_1) = K\left[V - \left(\frac{m_c}{\rho_c} + \frac{m_w}{\rho_w}\right)\right] \tag{2}$$

where, ρ_d (kg/m^3) is the target density of the foamed concrete. S_a is the empirical coefficient which is 1.2 for standard 52.5 Portland cement. m_c (kg) and m_w (kg) is the mass of cement and water separately. V (m^3) is the volume of foamed concrete, equal to 1 m^3. V_1 (m^3) and V_2 (m^3) are the volume of cement paste and foam respectively. ρ_c (kg/m^3) and ρ_w (kg/m^3) are the densities of cement and

Table 2
Density of different foam, wt%.

Foaming agent	Type	Foam density (kg/m^3)
AS	Animal based surfactants	53
SS	Synthetic surfactants	118
PS	Plant based surfactants	48

Table 1
Compositions of cement as determined by XRF, wt%.

Oxide	CaO	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	SO_3	K_2O	Na_2O	LOI
Content	63.97	20.97	4.69	3.02	0.22	0.63	2.56	0.61	0.09	3.84