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Properties of foamed concrete containing water repellents

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HIGHLIGHTS

- A foamed concrete modified by water repellent with low water absorption is prepared.
- The effects of water repellent on the physical and mechanical properties are investigated.
- The hygroscopic fitted curves from KUM and CUB models are established.

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ABSTRACT

It is generally known that the physical and mechanical properties would be greatly degraded after water or moisture transferring into the foamed concrete. In this study, a foamed concrete with a low density of about 550 kg/m^3 is prepared using ordinary Portland cement, and three types of water repellents including potassium trimethylsilanolate (PT), calcium stearate (CS) and siloxane-based polymer (SP) are employed to decrease the water absorption of the foamed concrete. The effects of the water repellent on the mechanical and physical properties of the foamed concrete, such as 7-day and 28-day compressive strength, thermal conductivity, sorptivity and hygroscopicity, are studied. The laboratory results indicate that the water repellents improve the compressive strength to some extent without sacrificing the thermal insulation property of the foamed concrete. The sorptivity evaluated by 48-h water absorption and strength retention coefficient (R_S) is significantly improved as increasing the content of water repellent. When 1.0% SP is used, the water absorption and R_S value of the foamed concrete with 28-day strength of 1.77 MPa and thermal conductivity of 0.150 W/m K are 2.5% (by volume) and 0.989, respectively. In addition, the contents of hygroscopic moisture [$W(\varphi)$] also decrease with the increasing content of water repellent. The hygroscopic fitted curves with high coefficients of determination obtained the KUM and CUB models have been proved applicable in exploring the relationship of the $W(\varphi)$ to the relative humidity.

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1. Introduction

In China, the energy consumption of construction industry has roughly 35 percent of total energy consumption in society [1]. In the past several years, lightweight concrete, aerated concrete and foamed concrete with excellent thermal insulating properties have been used as exterior wall materials and studied by many researchers [2–7]. In addition, the foamed concrete with high fluidity and low cement and aggregate usage is also applied to sandwich structures, earth-remaining walls and running tracks or playgrounds [8,9]. The common used foamed concrete is defined as pre-foamed foam concrete by adding the projected amount of foam into cement slurry.

The first modern foamed concrete prepared by Portland cement was reported in the twenty-twenties [10]. During the past decades, the improvement of foaming technology and the application of high-efficiency superplasticizers, foam stabilizers and early strength agents have substantially improve the engineering properties of the foamed concrete. And many researchers have studied the preparation methods, fresh properties, physical properties and mechanical properties in detail [4,6,11–15]. It is notable that the transfer of moisture or water into the foamed concrete has drawn increasing attention due to the significant impact of the climate change [13,16].

The permeability of the foamed concrete which depends upon its porosity and pore structure (such as pore diameter and continuity) is the main factor in determining the transport of moisture or water [17]. To understand the mechanism of water permeation in foamed concrete, sorptivity and hygroscopicity characterized by water and moisture (water vapour) absorption are the applicable

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parameters [18]. The properties of the foamed concrete after water immersion and hygroscopicity tests have been studied [19–22]. It can be concluded that the water or moisture absorption has significantly negative influence on the physical and mechanical properties of the foamed concrete, which may result in energy waste and failure cracks. As reported earlier, types of foam agents, densities and mineral supplementary materials for the foamed concrete are also the factors influencing the sorptivity and hygroscopicity.

Several researches have studied the moisture dynamics of foamed concrete and established some phenomenological models to guide the design of the foamed concrete [17,19,21]. Even so, the water absorption of foamed concrete prepared by cement, sand and fly ash with the dry density of about 900 kg/m^3 is about 30% (by volume of the concrete) and the moisture absorption of lightweight concrete prepared by cement and lightweight sand with the dry density of about 950 kg/m^3 is approximately 30 kg/m^3 under a relative humidity of 95% [13,18]. This implies that the foamed/lightweight concrete prepared at the optimal design also has a high water or moisture absorption. However, there are few studies reported on the improvement methodology of water absorption of foamed concrete.

In this study, ordinary Portland cement and silica fume are employed as cementitious materials to prepare foamed concrete with low dry density of about 550 kg/m^3. To decrease the water absorption, three different water repellents have been introduced into foamed concrete. The physical and mechanical properties have been tested and analyzed in laboratory. And the effects of water repellent on compressive strength and thermal conductivity are investigated. Based on the results of water immersion and hygroscopic tests, some numerical models are established and a foamed concrete with low water absorption is obtained.

2. Experimental procedure

2.1. Materials

Ordinary Portland cement (OPC) with a 28-strength of 56.5 MPa and silica fume (SF) achieved from Elken Materials are the selected cementitious materials to prepare low-density foamed concrete. Table 1 lists the chemical compositions of OPC and silica fume. The polypropylene (PP) fiber with a tensile strength of 800.0 MPa and modulus of 8.0 GPa is employed to improve the toughness of foamed concrete, and its length and diameter are 15.0 mm and 100.0 μm, respectively. In order to obtain an acceptable workability of the mixture, a type of naphthalene-based superplasticizer (SL) is introduced into each specimen. In addition, the composites of early strength and foam stabilizer agents (NAF) prepared in the laboratory are used. A protein-based foaming agent which can provide a more stable bubble network is used, and the density of the foam is about 70 kg/m^3.

The purpose of this study is to prepare a foamed concrete with excellent sorptivity and hygroscopicity and investigate the effects of water repellent on the properties of foamed concrete. Three types of water repellents are selected and they are potassium trimethylsilanolate (PT), calcium stearate (CS) and a type of siloxane-based polymer (SP), respectively. SP powder are prepared in the laboratory and CS is chemically pure. The detailed compositions of each mixture for contrast specimen and three series of specimens are presented in Table 2.

Table 1
Chemical composition of binders (% by weight).

Oxide	OPC	SF
SiO_2	21.6	92.40
Al_2O_3	4.13	0.80
Fe_2O_3	4.57	0.50
CaO	64.44	0.91
MgO	1.06	0.27
Na_2O	0.11	–
K_2O	0.56	–
SO_3	1.74	–
LOI (Loss on ignition)	0.76	2.0

2.2. Specimen preparation

A paddle mixer is used to produce foamed concrete mixture by adding the projected volume of foam. The different series of specimens are prepared by adding different types of water repellents as shown in Table 2. The preparation of the mixture includes three steps. Firstly, the predetermined amount of water was mixed with cementitious materials and admixtures and the stirring process lasts about 3 min in order to obtain a homogeneous mixture. And then, PP fibers are introduced into the mixture and mixed for about 5 min. Finally, the projected volume of foam is added immediately into the fluid mixture and the mixture is continued to mix in high speed until the foam is uniformly distributed in the mixture.

Then, the fluid foamed concrete is poured into the cube PVC moulds (150 mm × 150 mm × 150 mm) and the surface of each specimen is smoothed by hand only. Subsequently, the moulds are transferred to standard curing room with a temperature of 22 ± 2 °C and a relative humidity of 97 ± 2%. Within the initial 12 h of curing, the moulds are covered with wet linen in order to keep the volume stability of the foamed concrete. After 3 days of curing, the specimens are demoulded and stored in the curing room until testing age.

2.3. Property measurement

2.3.1. Compressive strength, thermal conductivity,

Before thermal conductivity tests, the specimens after 28 days of standard curing are oven-dried in a vacuum oven at 45 ± 2 °C. After 48 h of oven drying, the specimen mass is weighed out every 12 h until the mass variation among three consecutive testing results not more than 0.1% of the total mass of specimens. The finally constant mass is used to calculate the dry density of the foamed concrete specimens and the calculated values are presented in Table 2.

The thermal conductivity of each specimen is measured by using a KD2 Pro thermal properties analyzer (Decagon Devices, Inc., USA). This equipment has an electronically handheld controller and sensors of different sizes which should be inserted into the foamed concrete specimens. Each needle-like (single-needle or double-needle) sensor consists of a thermistor and a heating element. In this study, a single-needle sensor with a diameter of 2.4 mm and a length of 100 mm is used and it can measure the thermal conductivity ranging from 0.02 W/m K to 2.0 W/m K. In order to insert the sensor into the oven-dried specimens, a hole of the same size with the sensor should be drilled. Each measurement process continues at least 5 min and at least four measurements are taken for each foamed concrete specimen to ensure the accuracy of ±5%.

At 7 and 28 days of curing, the specimens are took out from the curing room. An MTS servo hydraulic testing machine with a capacity of 100 kN is employed to measure the compressive strength of foamed concrete. The loading rate is fixed at 0.5 mm/min and the strength is the mean value of five measurements to confirm the reproducible of experimental results. In addition, the strength values which are beyond ±15% of the mean strength value should not be used and the compressive strength presented in this study is the average of at least three testing results.

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