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Preparation and characterization of super low density foamed concrete from Portland cement and admixtures ☆

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HIGHLIGHTS

- Preparation of super low density foamed concrete, SFC, with dry density 150–300 kg/m^3, was investigated.
- Portland cement was used as binding material instead of rapid setting or hardening special cement.
- Chemically foaming process was adopted for SFC preparation.
- Modification of several properties related to engineering application of SFC was attempted and discussed.

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ABSTRACT

Foamed concrete with its super low density of between 150 kg/m^3 and 300 kg/m^3 was prepared by means of chemically foaming and so called mixing and foaming process in laboratory. Conventional Portland cement was selected as the main binding material instead of rapid hardening special cement such as sulfoaluminate cement. Chemical and physical admixtures were properly introduced for the regulation of the rheological property and hardening speed of the fresh cement mixture slurry as well as the physical properties of the hardened foamed concrete. The resultant foamed concrete with its curing age of 28 d thus obtained presents its compressive strength between 0.33 MPa and 1.1 MPa, water absorption between 6.6% and 8.3% and thermal conductivity between 0.05 W/mK and 0.07 W/mK.

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1. Introduction

As is well known, foamed concrete is a cement-based lightweight porous material and is usually prepared by means of the so called pre-foaming method with physically foaming and the so called mixing and foaming method with chemically foaming [1]. Different from structural concrete, foamed concrete has found its wide application in construction engineering especially for thermal or sound insulation, or for dead load reduction, or for vibration attenuation, or for void filling, etc. instead of mechanical purpose. The density of the typical foamed concrete being used in construction engineering generally ranges from 500 kg/m^3 to 1200 kg/m^3. Its corresponding thermal conductivity ranges from about 0.15 W/mK to 0.45 W/mK, and its corresponding compressive strength ranging from about 1.5 MPa to 6.5 MPa [2–8]. Recently, with the worldwide increasing demand for the energy supply under the precondition of the limited energy resources, energy saving or the high efficiency energy utilization in social and industrial activities becomes a principal policy for most of the countries. Research on the preparation and application of foamed concrete aimed at its thermal insulation purpose is therefore recently more and more getting its attention than ever before. It is a basic knowledge that the lower the density of the foamed concrete is the lower its thermal conductivity is, i.e. the better its thermal insulation effectiveness is. Low density foamed concrete is therefore anticipated when it is especially designed for thermal insulation purpose in order to acquire better insulation effectiveness. However, very rare research articles on foamed concrete with density less than 300 kg/m^3 so far have been seen in publication. This paper hereby reports the experimental research results on the preparation and characterization of the super low density foamed concrete, SFC, with its dry density between 150 kg/m^3 and 300 kg/m^3.

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2. Experimental details

2.1. Constituent materials

2.1.1. Cement

PO42.5 Portland cement in accordance with China national standard GB 175-2007, Common Portland Cement, was selected as the binding material for the preparation of SFC instead of some rapid hardening or fast setting special cement, such as sulfoaluminate cement, on account of its reliable long term durability and low cost and its easy availability. Table 1 lists the physical properties of the cement used in this experiment.

2.1.2. Mineral admixtures

Ultrafine ground granulated blast furnace slag powder, USP, with its Blaine specific surface area 800 m^2/kg, was used in experiment to regulate the rate and amount of hydration heat evolution and to control the temperature raise of the freshly placed foamed concrete in order to prevent it from uneven volume deforming or cracking.

2.1.3. Other chemical and physical admixtures

Hydrogen peroxide, H_2O_2, is selected as a chemical foaming agent to avoid the side effect such as retarded setting and delayed hardening of the cement paste caused by the introduction of some organic physical foaming agent which is believed to be one of the reasons causing the collapse or sinking of the freshly placed foamed concrete.

Polycarboxylate superplasticizer, SP, is used to reduce the *w*/*c* ratio of the cement mixture slurry as far as possible meanwhile keep its satisfactory flowability to allow the foam to be generated easily and disposed homogeneously among the freshly placed foamed concrete matrix.

Alkali free setting accelerator, SA, synthesized in laboratory with alumina sulfate as its main constituent and with its solid content 40% was selected for regulating the setting time of the cement in order for the mixture slurry to set and harden as quickly as possible immediately after foaming and placing, meanwhile to keep the mixture slurry with a good flowability before and during foaming.

Besides, polypropylene fiber, PF, and styrene-acrylate emulsion, SAE, and organic silicone waterproofing agent, OS, and foam stabilizer, FS, with sodium dodecyl benzene sulfonate as its main constituent were also introduced into the fresh mixture slurry of SFC, in order to improve the volume integrity and toughness and water resistance of the hardened foamed concrete.

2.2. Experimental procedure

2.2.1. Procedure for preparation of SFC

The preparation process of the so called SFC is as illustrated in Fig. 1. Cement, slag powder and water are first mixed in a lower speed of about 500 rpm for a short while, followed by addition of chemical and physical admixtures. The mixture is sequentially mixed in an increased speed of about 1000 rpm till it has changed into homogeneous and flowable slurry. After that the foaming agent is added into the mixture slurry quickly without stopping mixing. The mixture slurry is then discharged out of the mixer and placed into moulds immediately after the foaming agent starts to foam and its volume begins to expand. SFC specimen is thus prepared after sealed curing in mould for 24 h, followed by sequential curing in wet air with RH larger than 90% and temperature 20 ± 2 °C after demoulding.

2.2.2. Method of characterization

(1) Determination of compressive strength: Determination of the compressive strength of SFC is conducted in accordance with ASTM C 495, Standard Test Method for Compressive Strength of Lightweight Insulation Concrete. Foamed concrete cube specimens with its side length 100 mm are adopted and oven dried at 110 ± 5 °C for 24 h one day prior to the scheduled date of determination.

(2) Measurement of thermal conductivity: Thermal conductivity of SFC is measured in accordance with ASTM C518, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus on HFM 436 by NETZSCH. Square plate SFC specimens with side length 300 mm and thickness 30 mm are used for the measurement.

(3) Determination of dry density: Determination of the dry density is conducted in accordance with China national standard GB/T5486-2008, Test Methods for Inorganic Rigid Thermal Insulation Products. SFC cube specimens with curing age 28 d and with side length 100 mm are prepared and oven dried at 110 ± 5 °C till constant weight and then are weighed after cooling in dry air for every 3 h till the relative mass difference between the two successive weighed results is less than 0.2%. The dry density of the SFC specimen is thus calculated in the following equation:

$$\rho = 1000 \times M$$

where M is the mass of the SFC specimen measured, in kg. ρ is the dry density of the SFC specimen calculated, in kg/m^3.

(4) Water absorption: Specimens with square side length 150 mm and thickness 30 mm for water absorption determination are first oven dried at the temperature 70 ± 5 °C till constant, and are weighed after cooling in a sealed condition. The cooled specimens are then immersed into water with temperature 20 ± 3 °C for 3 h, and are weighed again after being taken out of water and wiping off the surface water by sponge. Water absorption is thus calculated according to the following equation:

$$\eta = \frac{V_w}{V} \times 100(\%) = \frac{G_w - G_d}{V\rho_w} \times 100(\%)$$

where η is the water absorption in %, V_w is the volume of the absorbed water by the specimen and V is the volume of the specimen in m^3, ρ_w being the density of water in kg/m^3, G_d and G_w being the mass of the SFC specimen before and after socking in water respectively in kg.

(5) Determination of flowability: Flowability of the fresh mixture slurry was evaluated in the following two ways, i.e. the direct visual observation of the mixing slurry expressed in easy or difficult to flow, associated with the passing time of a given volume of slurry through a small diameter pipe. The structural and dimensional information of the apparatus for the determination of the passing time is shown in Fig. 2, which comprises of an upside down cone connected with a pipe, just like a funnel. The volume of the cone is about 1000 cc, and the diameter of the connected pipe is 8 mm. Upon determination, 700 cc well mixed slurry is first filled in the cone and the connected pipe and is stopped by finger or something from flowing out of the apparatus. The passing time for the mixture slurry from its start of flowing out to the moment when 500 cc slurry passed through the apparatus is thus recorded and is used as an index to describe the flowability of the slurry. The shorter the passing time is, the better the flowability of the slurry is.

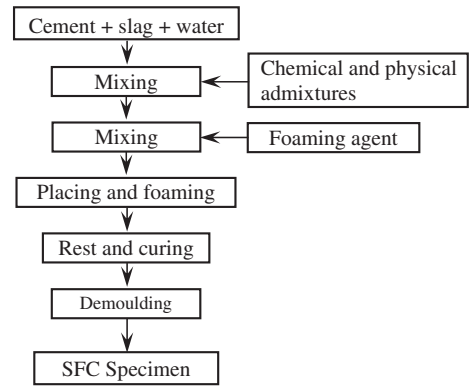

Fig. 1. Schematic diagram for the procedure of SFC preparation.

3. Results and discussion

As is mentioned above, common foamed concrete with its density between 500 kg/m^3 and 1200 kg/m^3 can be easily prepared by means of the so called pre-foaming process. However, sinking or collapsing of the freshly placed foamed concrete frequently occurs when its designed density is lower than 300 kg/m^3. It is believed that the shortage of binding material and the delayed setting and

Table 1
Physical properties of the PO42.5 Portland cement used in experiment.

Blaine (m^2 kg^{-1})	SO_3 (%)	MgO (%)	Soundness	Ig loss (%)	Setting time (min)		Bending strength (MPa)		Compressive strength (MPa)	
					Initial	Final	3 d	28 d	3 d	28 d
346	2.43	1.11	Good	2.98	172	221	6.2	9.3	29.7	53.3

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