Construction and Building Materials 135 (2017) 203–211

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Influence of high temperature on the residual physical and mechanical properties of foamed concrete

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HIGHLIGHTS

- The appearances for all samples were not changed obviously when the temperature lower than 200 °C.
- With the increasing of temperature, the density became lower and lower for all samples.
- A function among compressive strength, temperature and density was obtained.
- A prediction model to reflect the change law of elastic modulus with the densities and temperatures was deduced.

ARTICLE INFO

Article history:
Received 17 September 2016
Received in revised form 9 December 2016
Accepted 30 December 2016

Keywords:
Foamed concrete
High temperature
Compressive strength
Elastic modulus
Fire resistance

ABSTRACT

To study the influence of high temperature on the properties of foamed concrete, four densities of foamed concrete (300 kg/m^3, 450 kg/m^3, 600 kg/m^3 and 800 kg/m^3) were taken into account in a series of tests. The change laws of appearance, mass, compressive strength and elastic module at ambient temperature and after undergoing different high temperatures (200 °C, 400 °C and 600 °C) were presented. The results indicate that the appearances for all of four different densities were different. The cracks to be observed at the higher densities foamed concretes (i.e., 800 kg/m^3 and 600 kg/m^3). However, the pore connectivity and surface spalling phenomenon are easier to be observed at lower densities foamed concretes (i.e., 300 kg/m^3 and 450 kg/m^3). With temperature increasing, the density, compressive strength and elastic modulus became lower and lower for all samples, however some details are different. Furthermore, two predicting models to reflect the change laws of compressive strength and elastic modulus with different densities and temperatures are obtained and are verified by comparing the results with the experimental data and other proposed models in previous works.

1. Introduction

1.1. Significance

Fire disaster is one of the major disasters to destroy building structures. The stability of the building components are greatly weakened under high temperature, including compressive strength, tensile strength and so on [1–3]. Foamed concrete is either cement paste or mortar, classified as lightweight concrete, in which air-voids are entrapped in mortar by suitable foaming agent [4]. It is now widely used as exterior wall thermal insulation material or non-load bearing wall, since it has many featured advantages, such as excellent thermal insulation, low cost and fireproof [5,6]. However, foamed concrete has the characteristics of high porosity, the structure performance is easy to change under fire condition [7,8]. Therefore, it is of great significance to study the influence of high temperature on the properties of foamed concrete.

1.2. Research status

Fire resistance of foamed concrete has attracted a lot of researchers. Researchers have been investigating for many years,

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http://dx.doi.org/10.1016/j.conbuildmat.2016.12.223
0950-0618/

and the main contributions include: Mydin and Wang [8] reported the results of experimental and analytical studies to investigate the mechanical properties of foamed concretes with two different densities (650 and 1000 kg/m^3) under high temperatures. The experimental results consistently demonstrated that the loss in stiffness of foamed concrete at elevated temperatures occurring predominantly after about 90 °C, regardless of density as water expands and evaporates from the porous body. This research has also found that the mechanical properties of foamed concrete can be predicted using the mechanical property models of normal weight concrete. Kearsley and Mostert [9] studied the effect of cement composition on the behaviour of foamed concrete at high temperature, and concluded that foamed concrete containing hydraulic cement with an Al_2O_3/CaO ratio can withstand temperatures as high as 1450 °C without any damage. Sayadi et al. [10] and Vilches et al. [11] demonstrated the effects of expanded polystyrene particles (EPS) on fire resistance, and concluded that the volume of EPS increasing caused a significant reduction of fire endurance. Jones and McCarthy [12] summarized that, as compared to vermiculite concrete, lower densities of foamed concrete exhibited better fire resistance. Othuman and Wang [13] presented two methods to determine thermal conductivity values of lightweight foamed concrete (LFC) at elevated temperature, furthermore, they concluded that LFC offers a feasible alternative to gypsum as the construction material for partition walls.

1.3. Objectives

The objectives in the previous works aimed at mid to high densities of foamed concrete (>500 kg/m^3). However, it all known that when the foamed concrete is used as insulation material, its density should be as low as possible on the premise of ensuring other properties to reach the insulation effect. What about the fire resistance for low densities (<500 kg/m^3) foamed concrete? Furthermore, the existed theory present that at high temperature the heat transfer through porous materials is influenced by radiation, which is an inverse function of the number of air–solid interfaces traversed. With its lower thermal conductivity and diffusivity, the foamed concrete may result in better fire resistance properties, whether is it suitable for low density (<500 kg/m^3) foamed concrete. There is no established theory for these two questions. Therefore, four densities of foamed concrete (300 kg/m^3, 450 kg/m^3, 600 kg/m^3 and 800 kg/m^3) were prepared, and asset of tests were carried out, and the change laws of appearance, mass, compressive strength and elastic module at ambient temperature and after undergoing different high temperatures (200 °C, 400 °C and 600 °C) were presented.

2. Experimental details

2.1. Constituent materials

Combinations of the following constituent materials were used to produce the foamed concrete.

(1) Ordinary Portland cement (OPC): the cement used in this study is a Chinese standard (GB175-2007) 425# Portland cement [14].
(2) Water: the common tap water.
(3) Foaming agent: one type of commercial composite foaming agent is chosen from Hua-tai building materials development Co., LTD, Henan province of China. The foaming performance is shown in Table 1.

2.2. Mix proportions

There is no standard method for proportioning foamed concrete. Here we design them according to their dry density. The mix proportioning method used in the study described as follows:

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

where, ρ_d is the dry density of the designed foamed concrete (kg/m^3), S_a is the empirical coefficient, 1.2 is usually used for standard 425# Portland cement, M_c is the mass of cement (kg/m^3).

The foam volume can be obtained by the following equation

$$V_2 = K(1 - V_1) = K\left[1 - \left(\frac{M_c}{\rho_c} + \frac{M_w}{\rho_w}\right)\right] \tag{2}$$

where, V_1 and V_2 are the volume of cement paste and foam, respectively; ρ_c and ρ_w are the densities of cement and water respectively, which equal to 3100 and 1000 kg/m^3; M_c and M_w are the cement and water respectively. In this paper, M_w=0.45M_c, as the binder ratio is constant 0.45; K is a coefficient, it is decided by the foam quality, generally ranging from 1.1 to 1.3, the stability of the foam agent used in our tests is good enough, so 1.1 is used in this paper.

The mass of foaming agent can be obtained by the following equations

$$M_y = V_2 \rho_f \tag{3}$$

$$M_p = \frac{M_y}{\alpha + 1} \tag{4}$$

where, M_y and ρ_f are the mass and densities of foam, respectively; M_p is the mass of foaming agent, α is the dilution ratio, 20 is used in this paper.

Four densities of foamed concrete, 300, 450, 600 and 800 kg/m^3, were cast and tested. Further details of the mix constituent proportions of all densities are outlined in Table 2.

2.3. Specimen preparation

According to Table 2, the measured cement and water were added into blender and mixed at first, meanwhile the foam was manufactured, after the cement paste mixing finished. The chosen amounts of the foam were added into the slurry, and mix 2–3 min in a high-speed (about 60–120 r/min). When the cement slurry and foam are mixed evenly, the foam slurry preparation is completed. Then, it was poured into the moulds. The specimens were removed from moulds after 24 h of casting and then seal cured in curing tank for 28 days. After that, the specimens were removed out and shaped to standard samples to further tests (Ø 50 mm × 100 mm).

2.4. Heating of specimens

The heating cabinet dimension is 80 cm × 60 cm × 60 cm, and the heating function is realized by the 8 heating resistance wires at both side. Its maximum operating temperature can reach 800 °C. From this figure it can be seen that if we want to heat to 200 °C, 400 °C and 600 °C, the required time is 9 min, 40 min and 150 min, respectively. In these heating tests, to show the influence of high temperature sufficiently, all of the heated samples undergoing 60 min constant temperature after they reached the target temperature.

2.5. Mass measurement and density calculation

1) Ambient temperature: Choosing three standard specimens (Ø 50 mm × 100 mm), gauging their actual dimensions to obtain their volume, and then putting the specimens into