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Utilization of original phosphogypsum for the preparation of foam concrete

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HIGHLIGHTS

- Large dosage of PG without pretreatments was utilized to manufacture foam concrete.
- This process reduces the secondary pollution and save energy compared with the traditional process.
- The effect of preparing parameters of foam concrete on mechanical properties was investigated.
- Performances of foam concrete like compressive strength and thermal conductivity are satisfactory.

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ABSTRACT

Original phosphogypsum (PG), which is a waste of phosphoric acid manufacturing by dehydrating process, was used as raw material for manufacture of foam concrete. It was prepared by adjusting the mix proportion of the untreated phosphogypsum and a small amount of cement, GGBFS and quick lime, meantime, mixing with foam. A series of manufacturing parameters were investigated to determine the performance of specimens in this work, such as accelerator, quick lime, PG, supplementary cementitious materials and foam content, water to solid ratio, curing regimes etc. The results show the most excellent content of PG was 45–55%, cement to GGBFS ratio was 1, quick lime 4%, sulphoaluminate cement 2%. In the case of mixed without water reducing admixture, the W/S (water to solid ratio) from 0.4 to 0.5 is excellent. Most of the PG are as filler, and there is a small amount of sulfate in the PG also played a role in stimulating calcium silicon materials and generating ettringite to enhance compressive strength. Carbonation resistance of PG-cement-GGBFS system is better than PG-cement-FA system. The thermal conductivity of different density grade met the requirement of a Chinese standard. The principal minerals in PG foam concrete are needlelike AFt, floccular C-S-H and unreactive plate gypsum.

1. Introduction

Phosphogypsum (PG) is a waste of phosphoric acid manufacturing by dehydrating process. It is a fine powder with high calcium sulfate content, which also contains a little amount of impurities like phosphates, fluorides and organic matter [1,2]. About five tons of PG are generated per ton of phosphoric acid production. With the rapid development of the phosphate fertilizer industry, global emissions in phosphogypsum are more than 150 million tons every year. In China, the amount of phosphogypsum has exceeded 250 million tons with more than 55 million tons of growth rates each year [3–5]. When the large amount of phosphogypsum is dumped on land, it may result in the rapid change in pH, which can affect most species of fish, aquatic life and vegetation [6]. The unscientific discharge of phosphogypsum not only leads to serious environmental contamination, but also occupies considerable land resource [7]. Therefore, low-cost, large-scale processing technology is needed to consume such a large amount of PG.

Strong efforts have been made in the comprehensive utilization of phosphogypsum. Such as using phosphogypsum as set retarder in Portland cement [8], soil stabilization [9], phosphogypsum plates [10], anhydrite cement [11], lime–fly ash–phosphogypsum binder [12], high-strength gypsum [13], calcium sulfate whiskers [14], hollow blocks [15], cementitious material [16], non-fired bricks [17] etc. However, in most of the related studies above, the consumption of phosphogypsum is too little, which cannot satisfy the purpose of mass consumption. Some of these studies meet

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the demand, but they must do some pretreatment for phosphogypsum, like thermally treated or washed, which may consume a large amount of energy, and produce secondary pollution that leads to cost increase. Hence, it starves for large-scale and low-cost processing technology. Yang et al. [18] utilized PG as raw material for the preparation of non-autoclaved aerated concrete. However, the shrinking, carbonization and water absorption are serious due to the large number of inter-connected air voids in the aerated concrete.

Now there are many ways of high value-added utilization, but only used in building materials can achieve the goal of consuming great quantities of PG. “The 12th five-year plan for energy conservation and emissions reduction in the aspect of building materials” in China makes clear that government encourages the development of the use of industrial waste to produce lightweight construction materials, the proportion of which will be 65% above by 2015, and the products can enjoy the exemption [19]. Thus, lightweight construction materials will get broad prospects for development. As lightweight building materials have been widely accepted by the market gradually, and the quality and the function of which are improved constantly, the demand of these materials will increase greatly in the future. The properties of lightweight concrete can be exploited in many ways from its use as a primary structural material to its incorporation into structures for the enhancement of thermal insulation [20]. Foam concrete, a kind of building insulation materials with energy-saving production and less raw materials consumption, can get more favourable.

In this work, original PG was used as raw material for manufacture of foam concrete. Foam concrete contains less connected air voids, which yields a lower carbonization, water absorption and reduction in compressive strength. Besides, the product has excellent thermal and sound insulation performance, low thermal conductivity and non-combustible. Its properties give them excellent potential in the field of thermal insulation to provide building energy efficiency and fire prevention. Steam curing was adopted in this work, which can facilitate the strength development of foam concrete and reduce energy consumption and costs in the production process. A series of technological parameters were investigated and then the relative performances of the product were tested.

2. Experimental details

2.1. Constituent materials

PG foam concrete mixtures were produced by using PG, cement, ground-granulated blast-furnace slag (GGBFS) or fly ash (FA), quick lime, sulphoaluminate cement, water and foaming agent. PG was obtained from phosphate fertilizer plant, water content was 11.2%, the mean grain size (d50) was 25.3 μm and the PH value was 5.0. The X-ray diffraction (XRD) of PG is shown in Fig. 1. Cement used in this experiment was P.O 42.5R (Chinese standard: GB175-2007 [21]). The grade of GGBFS was S95 (Chinese standard: GB/T18046-2008 [22]). The main chemical components of above raw materials are shown in Table 1. Quick lime was bought from the market and the effective CaO content was 84.2%, the slake-temperature and slake-time were 92 °C and 4 min, respectively. Foam was produced by aerating the animal protein foaming agent (dilution ratio 1:20 by weight)

2.2. Preparation process of specimens

Weighed the raw materials in predetermined proportions and mixed them for 1 min. The dilute solution of admixture like superplasticizer was added into the dry mixture and mixed again for 3 min. When the slurry was homogeneous, added the preformed foam stirred in high-speed mixer and then mixed the slurry again. Next, the slurry was molded in 70.7 mm × 70.7 mm × 70.7 mm. After molding, the cubes were cured in different temperature steam curing for some hours. At last, PG foam concrete is gained after was dried at the temperature of 60 °C.

2.3. Test methods

Density test: Dry a group of three cubes at the temperature of 60 °C in electric thermostatic drying oven until the weight was constant; the weight to volume ratio is density.

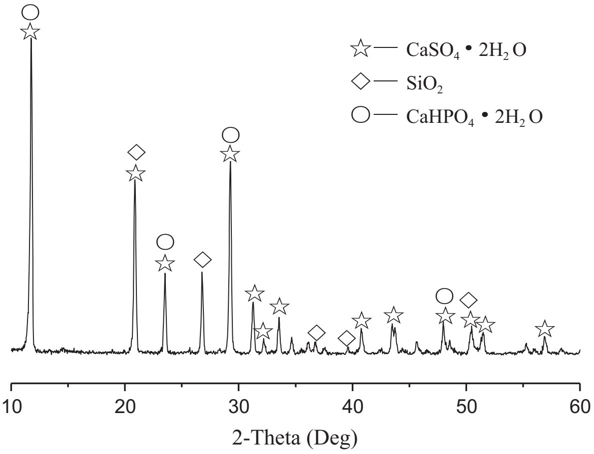

Fig. 1. XRD pattern of PG.

Compressive strength test: After density test, compressive strength was tested referring to Chinese standard (JG/T266-2011 [23]).

Thermal conductivity was tested by DRY-300F heat flow conductometer. The size of the specimens was 300 mm × 300 mm × 30 mm. Microstructures were studied by SEM, mineral phases were studied by powder XRD technique and chemical compositions were studied by XRF. Carbonization and shrinking were tested referring to Chinese standard GB/T11969-2008 [24].

3. Results and discussion

3.1. Effect of accelerator

As all known, it is very important that the adaption between the setting time of slurry prepared with a large dosage of original PG and the stable time of foam for the preparation of foam concrete. For the purpose of controlling the setting time of slurry, accelerator like sulphoaluminate cement was used. Effect of sulphoaluminate cement content on initial, final setting time and compressive strength of matrix specimens are shown in Table 2.

As shown in Table 2, the setting time of the slurry without accelerator is much longer than those of adding accelerator. The initial setting time reduced quickly from 476 min to 70–102 min, shortened 78.6–85.3%. Final setting time reduced to 320–461 min from 598 min, shorten by 22.9%–46.5%. With the increase of the accelerator content, the setting time showed a trend of decline. Compressive strength increases with the age increasing from 3 days to 28 days, but there is no significant effect on the compressive strength of 3 days, 7 days, 28 days of the matrix with an increase in sulphoaluminate cement content. The effect of sulphoaluminate cement content on the density and compressive strength of foam concrete is presented in Fig. 2. The mix proportion of foam concrete is as follows: quick lime 4% (mass percent, the same below), PG 50% (dry mass), cement 25%, GGBFS 25%, W/S (Water to solid ratio) = 0.5, foam 0.1%. The density of mixes increases ranging from 518 kg/m^3 to 591 kg/m^3. The compressive strength fluctuates with the increase of sulphoaluminate cement content. This is because PG has obvious retarding effect on early hydration of ordinary Portland cement, on the other hand, PG can promote early hydration of sulphur aluminate cement. The two kinds of effect lead to the volatility of compressive strength.

As can be seen, accelerated effect of the sulphoaluminate cement is apparent. Because anhydrous calcium sulphoaluminate in the sulphoaluminate cement can promote the early hydration of Portland cement, and generate ettringite crystal rapidly. Another reason is that ordinary Portland cement is high alkalinity cement and sulphoaluminate cement is low alkalinity cement, as a result, a small amount of sulphoaluminate cement instead of ordinary