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A comprehensive study on the production of autoclaved aerated concrete: Effects of silica-lime-cement composition and autoclaving conditions

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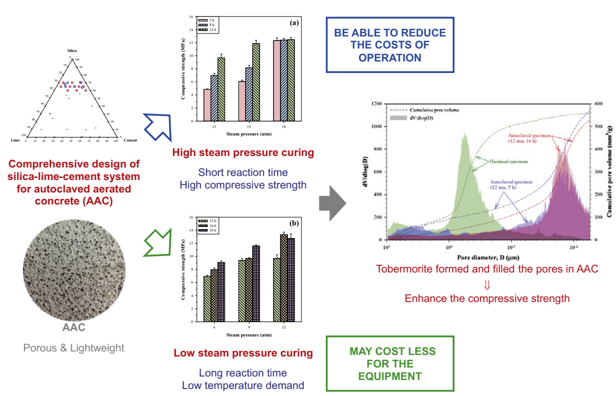
HIGHLIGHTS

- A comprehensive composition design for the production of autoclaved aerated concrete was studied.
- The effect of water-solids ratio on bulk density was more notable than that of foaming agent addition.
- High steam pressure curing can significantly reduce the reaction time and obtain high compressive strength products.
- Prolonging curing time was helpful to the development of compressive strength under low steam pressure conditions.
- Tobermorite formation and pores filling are curial to the compressive strength of autoclaved aerated concrete.

GRAPHICAL ABSTRACT



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ABSTRACT

This study describes the effects of raw mix composition, amount of foaming agent, water-solids ratio, steam pressure, and curing time on the characteristics of autoclaved aerated concrete (AAC). The bulk density, compressive strength, and microstructures of AAC specimens were examined, and X-ray diffraction, mercury intrusion porosimetry, and thermal analyses were employed. The bulk density of AAC was affected by the amount of aluminum powder added and water-solids ratio, and especially the latter. An increase in the amount of cement was not beneficial to the development of compressive strength. In contrast, autoclave curing greatly enhanced the compressive strength, and the AAC specimen autoclaved at 12 atm for 16 h had the highest compressive strength of 13.3 MPa. Increasing steam pressure can notably reduce the curing time, based on similar requirements of compressive strength. In contrast, prolonging curing time was helpful to the development of compressive strength under low steam pressure conditions.

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1. Introduction

Lightweight concrete has attracted greater attention in the last couple of decades, since urban buildings are now built higher and higher and there is a need to reduce their inherent weight. The use of lightweight concrete can also improve the seismic capability of a building [1], and moreover lowers the costs and difficulties in transportation and construction [2–4]. Lightweight concrete can generally be divided into two groups, namely lightweight aggregate concrete and aerated concrete. Lightweight aggregate concrete, as the name suggests, is a kind of concrete made by replacing normal aggregates with lightweight ones, thus reducing the bulk specific gravity. The use of lightweight aggregate concrete is basically identical to that of normal concrete, so that it can be used for structural units of a building and most of other concrete components [5,6]. However, the costs of manufacturing lightweight aggregate concrete are generally high, because lightweight aggregates are produced from a high-temperature sintering process [7]. Furthermore, the problem of uneven distribution of aggregates is very common, and this thus makes lightweight aggregate concrete unpopular in practice [8,9].

On the other hand, aerated concrete contains no coarse aggregates and is relatively homogeneous compared with lightweight aggregate concrete [10]. Aerated concrete, also known as cellular concrete, foam concrete, porous concrete, and so on, is produced with a cement or lime mortar, in which air voids are generated by a gas-forming or foaming process and then entrapped, and this therefore makes the material lightweight. However, the air voids in the aerated concrete diminish the mechanical strength [11], and an autoclave curing process is usually employed to remedy this defect. Under high-pressure steam conditions for curing, the gel-type calcium silicate hydrates (CSH) will become crystalline tobermorite, which then enhances the material's mechanical strength. The resulting material is called autoclaved aerated concrete (AAC), autoclaved lightweight concrete, or autoclaved cellular concrete.

The basic raw materials of AAC include silica sand, lime powder, and cement. In recent years, some substitute materials and industrial byproducts, such as coal-fired fly and bottom ashes [12,13], silica fume [14], mine tailing, and iron slag [15], have been studied, and there exists a wide variation in the raw mix compositions suggested by various authors [12,16–20]. The other significant variables are the particle size of raw materials, the amounts of foaming agent and water added, and the autoclave curing conditions. Some studies [21,22] indicate that the particle size of quartz is an important factor in AAC production. Finer quartz is more reactive than coarser quartz, but it also promotes the formation of gyrolite, an undesirable mineral in AAC. Zhao et al. [23] noted that the tobermorite gradually transformed to xonotlite with continuous autoclaving, a finding which suggests that immoderate autoclave curing may harm the properties of AAC.

While many studies have been done on AAC production, and indicated the effects of different process conditions, some of the conclusions are inconsistent and few works have made a comprehensive study under fully controlled conditions. Accordingly, the purpose of this study was to investigate the effects on the AAC characteristics by widely testing a set of variables, including raw mix composition, amount of foaming agent, water-solids ratio, steam pressure, and curing time. The bulk density and compressive strength of the AAC products were determined, and the microstructures, including crystalline compositions, hydration products, and pore size distribution, were analyzed in this work. By eliminating the influence of particle size, the effects of silica-lime-cement composition on the properties of AAC products should be revealed. Moreover, increasing the steam pressure is theoretically beneficial to the reduction in reaction time, but it is needed to further examine the appropriate combinations of steam pressure and reaction time.

2. Materials and methods

2.1. Raw materials and composition design of AAC

The silica-lime-cement ternary diagram of the raw mix compositions of AAC is shown in Fig. 1, based on a review of several studies on AAC production from the 1980s to the present [12,16–20]. The figure shows that the differences in the amounts of lime and cement are greater than the differences in the amounts of silica. Lime and cement both varied between 5 and 30 wt%, while silica varied between 60 and 70 wt%. The experimental design of the AAC raw mixes in this study was based on the results of literature survey, and the exact proportions of the raw materials are given in Table 1.

In order to minimize the influence of particle size, the particle size distribution of raw materials was determined and controlled at the same level for all the samples. Fig. 2 shows the particle size distribution of silica, lime, and cement used for AAC production. The high-purity silica powder (99.5%) was purchased from Alfa

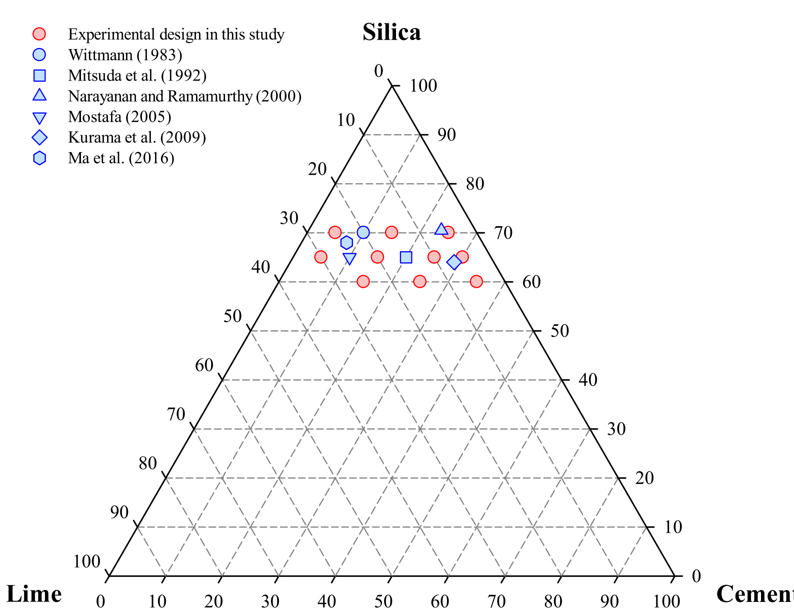

Fig. 1. Silica-lime-cement ternary diagram for raw mix compositions of AAC.