Construction and Building Materials 146 (2017) 403–409

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical strength and durability performance of autoclaved lime-saline soil brick

Tung-Chai Ling [a,b], Kim Hung Mo [c,*], Lie Qu [d,e,*], Jiujun Yang [d,e], Lei Guo [d,e]

[a] College of Civil Engineering, Hunan University, Changsha, Hunan, China
[b] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region
[c] Department of Civil Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia
[d] Department of Materials Science and Engineering, Tianjin Chengjian University, China
[e] Tianjin Key Laboratory of Soft Soil Environmental and Engineering Properties, China

HIGHLIGHTS

- Autoclaved lime-saline soil brick was produced.
- Good dry-wet and freeze-thaw durability of autoclaved brick.
- Incorporation of up to 40% fine sand improved durability of autoclaved brick.

ARTICLE INFO

Article history:
Received 15 October 2016
Received in revised form 25 March 2017
Accepted 12 April 2017

Keywords:
Saline soil
Autoclaved brick
Calcium silicate brick
Durability properties

ABSTRACT

The growing demand of building materials in China has intensified the search for a greener and more environmental friendly substitute for conventional clay brick. One of the proposed alternatives is the use of brick incorporating saline soil as replacement for conventional siliceous sand. Saline soil is available in abundance in China but because saline soil contains high content of soluble salts, it is unsuitable for agricultural use. It is therefore interesting to explore the utilization of saline soil in the production of autoclaved brick for both economic and environmental benefits. As part of research project in producing lime-saline soil bricks, this paper presents an investigation of the mechanical strength and durability properties of the bricks with varying amount of fine sand replacements (10%, 20%, 30% and 40%) for saline soil. The results revealed that in general, the lime-saline soil bricks had good water resistance in terms of softening coefficient and drying-wetting durability as no reduction in compressive strength was observed. Incorporation of fine sand, particularly at 40%, also resulted in improvement in the drying-wetting and freeze-thaw durability properties of the autoclaved lime-saline soil bricks. In addition, autoclaved lime-saline soil sample exhibited enhanced salt fixing ability compared to raw saline soil sample. Overall, it can be said that the autoclaved lime-saline soil brick exhibit good properties in terms of mechanical strength and durability performances, and further improvement can be achieved through the incorporation of up to 40% fine sand.

1. Introduction

In the past, production of clay bricks consumed huge amount of clay in China. Approximately 1.3 billion m^2 cultivated area has been destroyed and about 70 million tonnes of coal has been consumed as a result of clay bricks production over the last 50 years [1]. This common problem around the world has resulted in efforts to partially replace clay with recycled waste materials such as slag [2], pumice [3], waste marble [4], paper waste [5], waste glass [6], bagasse and rice husk ash [7] in the production of bricks.

On the other hand, autoclaved lime-sand brick, also known as calcium silicate brick, offers a greener alternative without the use of clay. Autoclaved lime-sand brick is considered to be a more environmental-friendly building material as it combines both lime and siliceous sand as the main raw materials. After curing in high-pressure autoclave, brick could achieve a high compressive strength, high water resistance and freeze-thaw durability [8]. Since the technology behind autoclaved lime-sand brick depends

* Corresponding authors at: Department of Civil Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia (K.H. Mo); Department of Materials Science and Engineering, Tianjin Chengjian University, China (L. Qu).
E-mail addresses: khmo@um.edu.my (K.H. Mo), qul@163.com (L. Qu).

http://dx.doi.org/10.1016/j.conbuildmat.2017.04.106
0950-0618/

primarily on the lime-silica reaction, such concept offers a greater opportunity in re-using industrial by-products or waste materials, particularly those which are rich in silica, in combination with the main materials. Moreover, incorporating the by-products could reduce the use of natural sand in the brick, and this helps in moderating the issue of sand depletion.

Over the years, research has been carried out to incorporate industrial by-products to produce autoclaved lime-sand brick. In particular, researchers have explored the possibility of incorporating fly ash to produce autoclaved lime-sand bricks [9,10]. Qin et al. [11] explored the usage of waste lime mud from papermaking process as source of lime as well as fly ash to produce autoclaved lime-sand bricks. Fang et al. [8] and Zhao et al. [1] utilized low-silicon tailings such as copper and hematite, respectively to produce autoclaved lime-sand brick which conformed to the requirements of the standard GB11945. Besides industrial by-products, building and demolition waste materials could be incorporated to replace natural sand in the autoclaved lime-sand brick as reported by Connan et al. [12] and Schuur [13], where clay brick wastes and concrete aggregate wastes were used, respectively. Sludge waste from water treatment plant [14] and deep bed filtration of beverages [15] were also used at low percentages in the bricks to reduce sludge waste disposal problems. The concept of introducing industrial by-products or waste materials not only ensures the sustainability of bricks production, more importantly waste management problems could be addressed at the same time.

In China, there is huge amount of saline soil, covering an area of over 3.6×10^7 hm^2 and accounts for 4.88% of the available land area in China [16]. Saline soils are soils which contain high amount of soluble salts and have adverse effect on growth of most crops. Proper management and treatment had to be carried out to prevent detrimental salt accumulation of the soils and maintain soil quality. However, if left untreated, areas with saline soil will be of waste and could induce negative environmental effects to the surroundings. Therefore, in terms of economic and environmental point of view, it is encouraged to explore possible usage of the saline soil. Although utilization of saline soil in engineering applications is very limited thus far, recent report showed that saline soil can be potentially be used to produce stabilised compressed earth brick [17]. Moreover, it was revealed that saline soil has potential pozzolanic activity due to the similar chemical and mineralogical components to fly ash [17]. Therefore, the use of saline soil as silica source for the lime-silica reaction in the production of autoclaved brick could be an interesting prospect in an effort to further enhance the environmental sustainability of brick production.

Considering that there is very limited literature available on the use of saline soil in building material, apart from the necessary strength and mechanical performance, it is also essential to ensure the durability properties of the resulting autoclaved lime-saline soil brick. Bricks with good durability properties ensure that structures built out of the bricks could withstand natural weathering effects, and require lower costs for maintenance, refurbishment, repair etc. in the long run. As part of the research project in exploring the use of saline soil to produce autoclaved lime-saline soil brick, this paper focuses on the investigation of the relevant durability properties of brick such as water resistance, durability towards dry-wet and freeze-thaw cycles, as well as the salt fixing ability of the brick. In particular, the effect of fine sand on these durability-related properties of autoclaved lime-saline soil brick was examined.

2. Materials

Saline soil used in the investigation was obtained from the Tianjin Binhai New District coastal area. The major chemical components of the saline soil are listed in Table 1 while the salt content in the saline soil is shown in Table 2. Based on XRD patterns shown in Fig. 1, the main mineral constituents of saline soil are quartz, albite, mica, feldspar and calcite. After grinding for 30 min, the saline soil had median particle size d_{50} of 14.95 μm, and about 60% of the milled saline soil had particle size in the range of 1–20 μm. The particle size distribution is given in Fig. 2.

Lime which contained 98.0% of calcium oxide was used as activator for the saline soil. Different sizes of quartz sand, denoted as 'quartz powder' and 'fine sand', were used as partial replacements for saline soil in the production of the autoclaved lime-saline soil brick. Quartz powder having a similar grain size (about 20 μm) as the ground saline soil was used to provide additional silica source to enhance the lime-silica reaction, whereas fine sand with a diameter ranging from 0 to 4.75 mm (fineness modulus of 2.4) was used as fine aggregate.

The mix proportions are given in Table 3. The control mix consisted of 55% saline soil, 20% quartz powder, 10% fine sand and 15% lime as the solid materials. The variable investigated in this research is the different replacement levels of saline soil with fine sand, namely 10%, 20%, 30% and 40%. The water-to-solids ratio (w/s) was fixed at 0.2 for all cases and 1.0% dosage of superplasticizer (SP) was added to all mixes.

For the preparation of the autoclaved bricks, the materials were initially mixed together (Fig. 3a) for 4 min. The materials were then filled into prismatic moulds measuring $40 \times 40 \times 160\ mm^3$ and compressed. This was followed by dry curing at temperature of 40 °C for 24 h before de-moulding of the specimens. After de-moulding, the specimens were subjected to autoclaving at a temperature of 175 °C for 3 h (Fig. 3b). An additional mix E5 was also prepared using the same proportion of materials as mix E3, and the specimens were autoclaved at temperature of 175 °C for 6 h (Table 3). This was done to facilitate the investigation of the effect of autoclaving period on the strength and durability properties of autoclaved lime-saline soil brick.

3. Testing methods

3.1. Compressive strength and softening coefficient

The compressive strength test was carried out according to ASTM C349. In addition, softening coefficient of a brick is examined to identify the ability to maintain its original properties when the material is affected by water in a long term. In this investigation, the softening coefficient, K is defined by:

$$K = P_1/P_0 \quad (1)$$

where P_1 is the compressive strength of surface dry brick after immersion in water for a period of 24 h (MPa) and P_0 is the compressive strength of brick without immersion in water (MPa). The test results were the average of three measurements.

3.2. Drying-wetting durability

The durability towards drying-wetting cycles of the brick specimens was tested in accordance to GB11975-89. A total of 20 dry-wet cycles were performed in this investigation. The density and compressive strength of the brick specimens were determined after every 2 cycles of drying-wetting. The hardened density of the bricks were determined according to ASTM C642.

3.3. Freezing-thawing durability

The testing for freezing-thawing durability for the brick specimens was performed based on GBJ82-85. A total of 20