Construction and Building Materials 71 (2014) 602–609

Contents lists available at ScienceDirect

Construction and Building Materials

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

Inorganic stabilisation methods for extruded earth masonry units

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HIGHLIGHTS

- Use of cement and lime soil stabilisation.
- Soil and method of commercially produced extruded bricks is used.
- Bricks tested in compression following wet and dry conditions.
- Initial curing temperature is varied and shows to impact early age strength development.
- The stabilisation process for extruded clay masonry is different to other earthen construction methods.

ARTICLE INFO

Article history:
Received 12 May 2014
Received in revised form 23 August 2014
Accepted 27 August 2014
Available online 25 September 2014

Keywords:
Cement
Lime
Compressed earth block
Natural building material
Strength

ABSTRACT

Addressing the challenges of embodied environmental impact of materials has led to growing interest in the use of earth as a construction material. Adopting large-scale commercial methods of extruded brick production has potential to overcome many of the existing barriers of adoption. Without the firing the bricks will have a significantly lower embodied environmental impact and similar dimensions (just over 100 mm thick in the UK) to conventional masonry. However, the wider adoption of 100 mm thick unfired earth masonry is dependent on its suitability for use in structurally load-bearing applications. Currently the greatest barrier to earth masonry adoption is the durability of the material when subjected to high moisture contents. Accidental or intentional wetting of a 100 mm thick load bearing unfired earth wall could lead to disproportionate collapse unless the moisture resistance is improved.

To overcome the concern of elevated moisture contents, a common approach is to chemically stabilise the soil using either cement or lime. While there has been research into the use of cement and lime for other forms of earth construction, their use for extruded earth bricks has not been investigated in depth. The source materials and inherent physical properties of extruded earth bricks are different to other forms of earthen construction. Therefore the suitability of cement and lime to stabilise soil for the purpose of extruded earth bricks requires investigation.

This research demonstrates the improvement in 28 day compressive strength, with a range of cement or lime contents and three initial curing temperatures. Small scale bricks were tested in both the ambient environmental conditions and following 24 h of full submersion in water. Key factors, such as density and moisture content, are shown to be important for compressive strength development. The effect of stabilisation has been shown to be more important as a determinant for strength than density and moisture content alone.

1. Introduction

Earthen construction has been used for thousands of years, but only relatively recently has there been a focus on quantifying and understanding the engineering properties for potential structural applications [7]. The interest of earthen construction methods is largely due to concerns of embodied carbon of construction materials. Meeting structural requirements, while using existing methods of construction, requires development and innovation with earthen materials and techniques.

1.1. Unstabilised earth masonry

Heath et al. [6] investigated the properties of 12 different commercially produced unfired clay bricks, provided by different manufacturers in the UK. The bricks were produced using the same process that is used for large scale fired brick production, however

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http://dx.doi.org/10.1016/j.conbuildmat.2014.08.094
0950-0618/

without the use of the kiln for firing. Heath et al. [7] presented the feasibility of using these unfired clay bricks as a replacement for concrete blocks for some domestic buildings, demonstrating the structural capacity of the units, however there were concerns about water resistance.

The greatest single barrier to unfired earthen construction is the low strength of the material when subject to high moisture contents. While this can be considered as an accidental case, the structural use of 100 mm thick unfired unstabilised earth units is currently not recommended because of the danger of disproportionate collapse. The potential for disproportional collapse has led to redundancy through thicker walls and has resulted in wall thicknesses of rammed earth and cob structures between 300 and 500 mm. Conventional masonry structures typically use 90–100 mm thick walls for internal partitions and the internal leaf of external walls. Adopting this thickness for unfired clay will overcome many barriers concerning the manufacture, construction and in-life use of the material. However, with a reduced wall thickness compared to typical earthen structures, there is reduced material redundancy and issues regarding high moisture contents arise again. To use unfired earth bricks require either a change in the way buildings are designed, constructed and habited, or the material needs to be enhanced to overcome the inherent low performance in elevated moisture conditions. Addressing this single issue, by creating low environmental impact bricks that have comparable performance and properties to current masonry units will negate many of the barriers.

1.2. Stabilised earth masonry

Soil stabilisation is a method of changing the inherent properties of soil to achieve improved properties. Many of the current methods were originally developed for ground stabilisation purposes but have been adapted for use in earthen construction. Inorganic methods of stabilisation typically involve the application of cement, lime and other hydraulic binders, as used throughout the concrete industry. The effect of the addition of these binders for rammed earth and compressed earth blocks is well documented [16,19,14] and this stabilisation can improve the strength, erosion resistance and dimensional stability. In addition to the methods used within concrete manufacture, inorganic stabilisers include the addition of any chemical compounds that are not based on hydrocarbons.

The addition of a chemical stabiliser will change the environmental impact of the unfired brick and potentially negating this benefit compared to alternative masonry units. While a full life cycle analysis is outside the scope of this paper, Maskell et al. [12] estimated the maximum stabiliser content based on the embodied energy and global warming potential compared with an Autoclaved Aerated Concrete (AAC), which was shown to have the lowest environmental impact of a range of typical masonry units. Based on this analysis, a maximum stabiliser content by mass of cement and lime was calculated to be approximately 8% and 7% respectively.

1.3. Inorganic stabilisation for extruded earth masonry

The focus of this paper is on the development of inorganic stabilisation methods that can be used with extruded unfired earth masonry units. The paper will investigate the addition of various mass fractions of cement and lime to a brick soil that is used for commercial fired brick production. Due to difficulties in full scale production, the laboratory scale production of small scale units developed by Maskell et al. [10] was used. For the purposes of this paper, a successful stabilisation method is one that achieves a saturated or 'wet' unit compressive strength of 1 MPa, without the reduction of a 'dry' compressive strength tested in ambient conditions. The mixing, extrusion and curing processes adopted in this study replicate those currently used in brick manufacturing plants in the UK. This approach was adopted to facilitate more rapid industry uptake.

2. Stabilisation mechanisms

2.1. Types of stabilisation

The three basic procedures of soil stabilisation are mechanical, physical and chemical [8]. Mechanical stabilisation typically means compaction of the material to change the density and mechanical strength. Physical stabilisation involves texture change and can involve heat and electrical treatment. Chemical stabilisation is the result of reactions either between the soil and the stabiliser or a reaction within the stabiliser only.

The extrusion process within a brick manufacturing plant imparts distinct physical and mechanical properties to the bricks [10]. Without a substantial capital investment, additional mechanical and physical stabilisation would not be feasible. The commercial production of bricks in the UK is predominantly by the extrusion process [2]. Although a brick plant may be able to incorporate an alternative physical stabilisation process, except for currently drying and firing the bricks, this would be an additional process and likely incur a significant capital cost. Within the current process, soils are typically blended together, and liquid chemicals are currently added to the mix to aid in the firing process. Therefore, there is clearly scope for chemical stabilisation through the addition of either a powder or liquid prior to extrusion without significantly adding or changing current practices.

Potential mechanisms by which chemical stabilisation of the soil can occur have been summarised by Tingle and Santoni [23] and include:

- Encapsulation of clay minerals.
- Cation exchange.
- Chemical breakdown of the clay.
- Absorption of organic molecules into the clay interlayer.

Various mass fractions of cement and lime could be added to the brick soil, which can then be extruded to achieve a stabilised brick. A review of the literature regarding the use of these stabilisers for other earthen constructions techniques is subsequently presented. Both cement and lime stabilisation are affected by curing temperatures and moisture conditions which affect hydration and other reaction rates, and these are discussed later.

2.2. Cement

The stabilisation mechanism of cement addition involves three processes including cation exchange, cementitious hydration and pozzolanic reactions [17]. The calcium silicate phases are regarded as more important in the stabilisation of soil [17]. The hydration of these phases produces calcium hydroxide that provides the calcium ions for cation exchange. When Portland cement is mixed with materials with a high clay content cations within the double layer of the clay minerals are exchanged with the higher valence calcium ion, which causes a decrease in the double layer. This occurs immediately and results in an increased tendency to flocculate that leads to a agglomeration and a decrease in plasticity. The hydration of the cement produces the cementitious materials of Calcium Silica Hydrate (CSH) and Calcium Alumina Hydrate (CAH). These hydrates encapsulate the clay particles and form strong bonds [17].