Construction and Building Materials 165 (2018) 333–345

Contents lists available at ScienceDirect

Construction and Building Materials

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

Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso

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HIGHLIGHTS

- Geopolymer binder based on local materials from Burkina Faso improves the usability properties of CEBs.
- Adding 10–20% geopolymer significantly improves the mechanical properties of CEBs, which become comparable to those of cement-stabilized CEBs.
- Thermal conductivities of geopolymerized CEBs are lower than those of cement-stabilized CEBs and are close to those of CEBs without stabilizer.

ARTICLE INFO

Article history:
Received 22 June 2017
Received in revised form 5 January 2018
Accepted 6 January 2018

Keywords:
Laterite
Metakaolin
Geopolymer
Physical and mechanical properties
Thermal characteristics

ABSTRACT

The main objective of this study is to evaluate the feasibility of stabilizing compressed earth blocks with a geopolymer binder that is less polluting than Portland cement. Thus, a performance evaluation of these materials compared to non-stabilized or Portland cement-stabilized earth blocks was the main aim this study.

The geopolymer was synthesized from a mixture of metakaolin and sodium hydroxide solution. Laterite formed the principal matrix of the bricks. Compressed Earth Bricks (CEBs) stabilized with 5, 10, 15 and 20% of geopolymer were produced and compared to both CEBs containing 8% of Portland cement and CEBs without stabilizer. After a cure of 14 days for the specimens without stabilizer and geopolymerized CEBs and 21 days for Portland cement-stabilized CEBs, the blocks were subjected to several characterization tests in order to evaluate their properties (physical mechanical and thermal properties).

The results showed that geopolymerization of CEBs significantly improved their mechanical performance and gave them thermal properties that were very similar to those of non-stabilized blocks. For a 15% geopolymer content, these materials displayed properties comparable to those of Portland cement-stabilized CEBs, in particular with regard to their stability in water.

1. Introduction

In Burkina Faso, the conventional building materials (cement) are relatively expensive because their raw materials are imported (clinker, mostly from the neighboring country of Togo), and are not affordable for a large proportion of the population. In this context, earthen materials remain the most economical way for these populations to build. Such materials, especially laterite, are found over almost all the national territory except the desert area in the far north and the extreme east of the country [1]. The earthen constructions made with adobes (banco) unfortunately suffer from cracking and degradations due to rainwater attacks, which compromise the durability of the buildings. Cement-stabilized compressed earth blocks (CEBs) have been developed to ensure better mechanical behavior [2] and better durability. Unfortunately, the use of Portland cement for CEB stabilization degrades the thermal properties of these materials, causing thermal comfort problems. Moreover, it has a negative environmental impact (significant emissions of greenhouse gases [3] related to the production of clinker).

Given these drawbacks of cementitious materials (high thermal conductivity, environmental damage and cost) and considering the poorly exploited clay potential of Burkina Faso, it is appropriate

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https://doi.org/10.1016/j.conbuildmat.2018.01.051
0950-0618/

and even indispensable to find alternative construction methods based on local materials that are energy-efficient and have limited environmental impacts. The possibility of stabilizing earth with a geopolymer binder appears as a solution to limit the production of greenhouse gases linked to the manufacture of cement and to address housing problems. This new method of stabilizing earthen blocks would also make it possible to improve the exploitation of Burkina Faso's clay potential.

Discovered in the 1970s [4], geopolymers can be synthesized at low temperatures (25–80 °C) using an alkaline solution and an aluminosilicate material. The synthesis generally involves materials containing amorphous silica, alumina, and alkali hydroxide (NaOH/KOH [5–7]). A wide range of aluminosilicate materials can be used for the synthesis of the binder. These include metakaolin [6,8], rice husk ash [9,10], fly ash [11] and volcanic slag [12]. Metakaolin appears to be the most widely used aluminosilicate material for making the geopolymer binder because it is easy to synthesize without CO_2 emissions its raw material (kaolin), is available throughout the world, and has suitable chemical and mineralogical properties (amorphous phase, silica and alumina content [13]). Moreover, its curing, which leads to the development of the binder properties, is carried out at relatively low temperatures [14]. Sindhunata [15] has shown that temperature is an accelerator of the kinetics of the polymerization reaction (dissolution of the aluminosilicates in the presence of the alkaline solution and condensation of the gels) and can significantly improve the mechanical performance. On the other hand, too high a temperature can weaken the structure and decrease the mechanical performance of the geopolymer. Muniz-Villareal et al. [16], in their study on the effect of temperature on geopolymers, found that the ideal temperature for obtaining better geo-polymerization was about 60 °C. Geopolymer is therefore an alkaline binder that is energy-efficient and more environmentally friendly than cement, for which it is a potential alternative.

The main idea of this study is to decrease the instability of earthen blocks by combining the earth with a geopolymer binder, the main properties of which are comparable to those of Portland binder. This will make the earthen blocks, which are considered to be the most accessible building materials, more stable. The development of this model will also make it possible to add value to local geo-resources.

In this study, the geopolymer binder was synthesized from a mixture of local clay (metakaolin), calcined at 700 °C, and an alkaline solution of NaOH (12 M) in a mass ratio (alkaline solution/solid material) of 0.8. Laterite was used as a raw material for the production of CEBs. The CEBs were stabilized with 5, 10, 15 or 20% geopolymer and were then compared to CEBs stabilized with 8% cement (considered as the reference material) and CEBs without stabilizer. After the physicochemical and mineralogical characterization of the raw materials, the physico-mechanical and thermal properties of the geopolymerized CEBs were evaluated and compared with those of the reference materials.

2. Experimental methods

2.1. Materials

2.1.1. Binders

The metakaolin (MK) used in this study has already been used for the synthesis and characterization of geopolymer binders. The conditions for obtaining this material are described in Ref. [17], that is to say the metakaolin (MK) was obtained by calcination a local clay material (K) at 700° C for 3 h (10 °C/min) and was then milled using a RETSCH-MS 100 and sieved at 100 µm. A 12 M sodium hydroxide solution obtained by dissolving the crystals in distilled water was used as an activating solution of the calcined material. The NaOH crystals used were of 99% purity. The geopolymer binder thus developed was expected to have a compressive strength of 14–25 MPa [17].

In addition, Portland cement of the CEM I type, from HEILDELBERG CIMTOGO, was used to stabilize the reference CEBs.

2.1.2. Granular material

The laterite (L) constituting the main matrix of CEBs was screened and sieved to 5 mm in order to obtain a material of 0/5 mm granular class according to the recommendations of the standard ARS 674 [18]. It was extracted from a local laterite quarry (Kamboinsé 12°29′24″N, 1°33′07″W and 317 m altitude) in Burkina Faso.

2.2. Stabilization process

The stabilization method adopted in this study was volumetric and took the density of the different basic materials (laterite, metakaolin and cement) into account. The optimum water content of the various dry mixtures was determined by the standard Proctor compaction test [19] shown in Fig. 1. The increase in water content at the optimum and the significant decrease in density for high metakaolin contents (10–20%) can be explained by the increase in the amount of fine particles in the mixture and the large surface area of the metakaolin particles. The overall CEB stabilization process is shown in Fig. 2 and can be divided into two parts.

2.2.1. Geopolymer stabilization

The mixture for the production of the CEBs was prepared in two stages. After homogenization of the dry mixture (laterite + metakaolin) for 10 min, water and the alkaline solution in a mass ratio (alkaline solution/metakaolin) of 0.8 were added. The amount of moisture (E_{hG}) needed was found by adjusting the optimum water content of the dry mixture (W_{Gi}, with i = 1, 2, 3 and 4 according to the metakaolin amount) by the amount of alkaline solution (S_a) (Eq. (1)). Thus, the CEBs were stabilized at a geopolymer content ranging from 5 to 20% ($CEB_{\_X\%G}$ with X = 5%, 10%, 15% or 20%).

$$E_{hG} = [((W_{Gi} \times M_s)/100) - S_a] \quad (1)$$

where E_{hG} is the mass of moistening water necessary for the stabilization of the geopolymer (g), W_{Gi} is the optimum water content of the dry mixture (laterite + metakaolin) (%), Ms is the mass of the dry mixture (laterite + metakaolin) (g), and S_a is the mass of the alkaline solution (g).

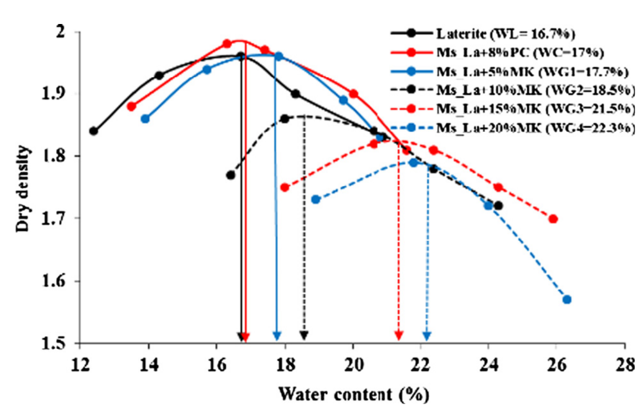

Fig. 1. Optimum water content of dry mixtures for CEBs.