A discussion of "optimisation of compressed earth blocks (CEBs) using natural origin materials: a systematic literature review"

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Highlights

The selection of earth should consider its reactivity in addition to its plasticity and texture

There is not a clear correlation between the thermal conductivity and density of CEBs

The correlation of compressive strength and density is better approached by an exponential law

The erosion resistance should be assessed based on eroded area in addition to the depth of erosion pit

Abstract

On 11 October 2021, this journal published a review article entitled "*Optimisation of Compressed Earth Blocks (CEBs) using natural origin materials: A systematic literature review*" [1]. The article made a very interesting state of the art review which allows the advancement of the knowledge on the improvement of the performance of CEBs. However, the present discussion points out that the review failed to recommend to take into consideration the reactivity, in addition to the parameters of texture and plasticity, for the selection of earth for the production of optimised CEBs. The review also simplified the relation between the thermal conductivity and density of CEBs, to a linear correlation. Moreover, the correlation between the compressive strength and bulk density is better approached by an exponential law rather than the linear law as was claimed in the review. Finally, the review should have recommended the consideration of eroded area, in addition to the depth of erosion pit, for the assessment of the erosion resistance of CEBs.

Keywords: reactivity of earth, selection of earth, optimization of CEBs, performance of CEBs,

1. Introduction

The recent article [1] systematically reviewed the current state of the art about the optimization of the performance of CEBs using natural origin materials. The article showed that the main reason of addition of fibers and powders/ ashes (mineral binders) to the earth is for the reinforcement and stabilization of the matrix, respectively. The review showed that the binders improves the compressive strength and the durability of CEBs; while the fibers tend to degrade those parameters and improve the thermal conductivity of CEBs [1]. The article went a step ahead in proposing some of the opportunities for the future researches to be addressed with regard to the durability and aging of fibers, computational and numerical modelling for the optimisation of the mixture design and the mechanical behavior, assessment of the environmental and economic impact, and promotion of the socio-economic acceptance of the material [1].

The present discussion elaborates on five points which were not fully / appropriately addressed: the reactivity of earth for the production of CEBs, the effect of binder on the physical properties of CEBs, the evolution of the thermal conductivity and compressive strength with the bulk density, and the erosion resistance of CEBs.

2. Reactivity for the selection of earthen materials

[1] stated that "*Atterberg limits represent a fundamental knowledge in the predictions of CEBs' mechanical behavior*." It is true that the literature has for so long considered the physico-chemical parameters related to the plasticity (interaction of earth with water) and the particle size distribution (PSD) for the selection of earthen material [2]. This is an appropriate approach, but it is not enough for selecting earthen materials for the production of optimised (stabilized) CEBs and other earth-based construction products. Recent studies have recommended to assess the parameters related to the chemical and mineral compositions of earth in order to better understand their influence on the behavior of earthen materials [3][4][5]. [5] showed that earthen material can be suitable for the production of CEBs stabilized with lime considering its reactivity; although it would not be considered if the plasticity and the PSD were the only selection criteria. In fact, the latter criteria are just guidelines which do not have necessarily to be complied by the earthen materials for their usage [6].

The reactivity of earth (with lime: $Ca(OH)_2$) was assessed through the evolution of the electrical conductivity (EC) of the solution made of earth and lime [5]. The decrease of the EC of the solution shows the consumption of Ca^{2+} and OH^- form lime by the earthen material through the pozzolanic reaction. The highest kinetics of the decrease of the EC is related to the highest rate of the pozzolanic reactivity of earth (with lime). [7] showed that the EC in solution containing kaolinite-rich earthen material decreases faster than in the solution containing quartz rich earthen materials. This allows the improvement of the mechanical and durability performances of optimised CEBs (stabilized with lime). However, more test procedures are still necessary for the assessment of the reactivity of earthen materials with other binders, and also considering different types earthen materials.

3. Optimum moisture content, bulk density and porosity of CEBs and effects of binders

[1] stated that "*To attain the maximum compaction, the water content within the mixture should be as close as possible to the Optimum Water Content (OWC), or Optimum Moisture Content (OMC), obtained by the Proctor Test*". Firstly, the proctor test is not the most appropriate test to determine the OMC of earth for the production of CEB. This is due to the fact that the proctor test is carried out in dynamic compaction mode, while the CEB are produced in static compaction mode. Instead of the dynamic OMC, it is recommended to use the static OMC which is obtained by compressing (statically) a series of material at different moisture content and of different humid mass until reaching the maximum mass of humid material that can be compressed in the mold. The moisture content from which this maximum mass is reached corresponds to the static OMC [8]. The static OMC is usually higher than the dynamic OMC, for the same earthen material, and also depending on their respective compaction energy.

In addition, it is very important to highlight the fact that the addition of chemical mineral binders, for the improvement of the properties of earth tends to impact the OMC of the mixtures. For example, the stabilization of earth using calcium carbide residue (CCR), a lime-rich by-product, in the range of 0 to 25% CCR has increased the static OMC following a relation OMC=0.21x%CCR+17% [7]. This agreed substantially with other studies where the earthen materials were stabilized with (industrial) hydrated lime [9] or metakaolinite-based geopolymer (MGP) activated with NaOH (12 M) [10].

The increase of the moisture demand to reach the appropriate consistency, of the mixture of earth and binder, to produce CEB has a decreasing effect on the bulk density of CEB. This is due to the fact that the production moisture would dry and results in porosity in the CEB. The resulting bulk density was considerably decreased from 1800 to 1477 kg/m^3 for the CEBs stabilized with 0 to 25 % CCR [11] and from 1840 to 1730 kg/m^3 for the CEB stabilized with 5 to 20 % MGP [10]. This was respectively accompanied by an increase of the porosity in the range of 35 to 45 % [11] and 35 to 38 % [10]. The increase of OMC of earth with addition of binders decreases the bulk density, by increasing the porosity, and eventually the water absorption (in the open porosity [1]), which have a negative effect on the durability of CEB. However, it opens up the opportunity for further optimization of the performances of CEB: the CEB which have low density (high porosity) would reach low thermal conductivity (better thermal performances [1]) and lower dead load (better structural performances in terms of higher coefficient of structural efficiency [1]). The latter applies for the CEB which keep their strength with decreasing bulk density [11].

Moreover, the mathematical expression of the porosity of CEB is not correct, as reported in equation 3 of [1]. The porosity should rather be determined as expressed in equation 1a or 1b of this discussion. In equation 1a, V_V is the volume of void space (such as air or saturating fluid in CEB) and V_T is the total or bulk volume of the CEB, including the solid and void components. In equation 1b, ρ_{CEB} is the bulk density of CEB, ρ_{fluid} is the density of the saturating fluid and $\rho_{particle}$ is the specific (real) density of particle (determined by pycnometer) constituting the CEB. Equation 1b becomes equation 1bc, if the void is saturated with air. Furthermore, the (water accessible) porosity of CEB can be determined by equation (1d) from the saturation experiment; where m_{air} is the mass of saturated CEB measured in air, m_{water} (kg) is the mass of the saturated CEB measured in water and m_{dry} (kg) is the mass of dry CEB.

$$P(\%) = \frac{V_V}{V_T} \tag{1a}$$

$$P(\%) = \frac{\rho_{particle} - \rho_{CEB}}{\rho_{particle} - \rho_{fluid}} \tag{1b}$$

$$P(\%) = 1 - \frac{\rho_{CEB}}{\rho_{particle}} \tag{1c}$$

$$P(\%) = \frac{m_{air} - m_{dry}}{m_{air} - m_{water}} \tag{1d}$$

4. Thermal conductivity and bulk density of CEBs

[1] stated that "*Fig. 12 represents this relationship, showing the trend of the reviewed fibre-reinforced CEBs and of the respective control sample (non-optimised CEBs). This important outcome, strengthened by the found* R^2 *value (0.92 for optimised CEBs), confirms the correlation between these two properties*". [1] went, on stating that "*Despite the similar trend, the same strong correlation between the bulk density and thermal conductivity was not found. Fig. 13 shows this relationship, where the coefficient of determination (R-squared value) describes a very weak correlation: only 0.365 for optimised CEBs and 0.213 for the non-optimised ones*". Such few data are insufficient to draw such conclusions. It is also unlikely for the CEB to reach the values of bulk density as high as 2800 kg/m^3 (see section 5).

A large number of data do not show a particular trend of the thermal conductivity of CEBs with density (Figure 1a). Figure 1a presents the trend of the thermal conductivity (λ=0.5-1.6 W/m.K) reported for CEBs which have the density (ρ) in the range of 1400 to 2200 kg/m^3 [10][11][12][13][14][15][16][17], compared to the trend for concrete [18]. Although, CEBs do not show a particular trend of the values of thermal conductivity [19], they reach relatively lower values than the concrete in the similar range of bulk density [18]. The lack of a particular trend of the thermal conductivity of CEBs is related to its variability which depends not only on the density (compaction pressure) of CEBs, but also the intrinsic properties of materials such as the type of earth, the type and content of stabilizer/ fiber, as well as the methods of production and characterization of CEB.

Figure 1b shows that the thermal conductivity of non-optimised (0 % stabilizer) CEBs ranges in 0.5-0.95 W/m.K for different types of earthen materials. It also shows that the thermal conductivity of optimised CEBs ranges in 0.5-1.1 W/m.K with respect to chemical stabilizer (cement, lime, or geopolymer) in the content of 0-20 % [10][12][15][20][21]. This is comparatively lower than the values (0.5-1.6 W/m.K) reached with respect to the bulk density of CEBs in the ranges of 1400-2200 kg/m^3 (Figure 1a). This confirms that the thermal conductivity of optimised CEBs is not only influenced by the stabilizer (type or content), but also the characteristics of earthen material itself, the compaction energy, and the measurement methods, among others [14].

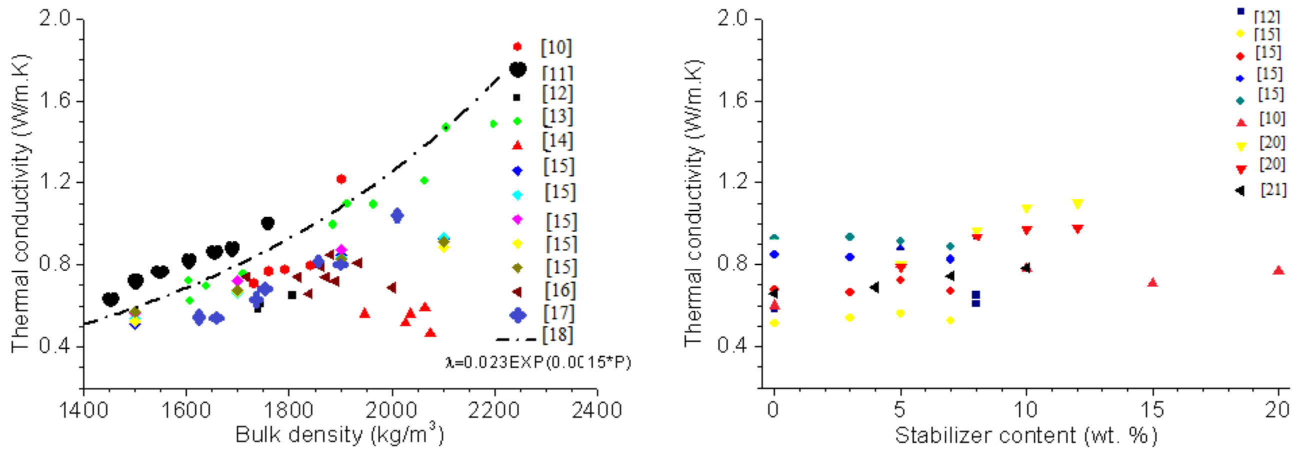
a
b

Figure 1. Evolution of the thermal conductivity with: a) the bulk density, b) stabilizer content of CEBs stabilized with binder

More specifically, it was reported that the thermal conductivity is less influenced by the composition of CEBs and lacks an obvious trend (increase or decrease) with small addition (≤10 %) of cement [12] [15]. However, the thermal conductivity ranges from 0.15 to 1.8 W/m.K for clay, 0.3 W/m.K for Portland cement, 0.4-0.7 W/m.K for cement paste (1900-2100 kg/m^3), and from 0.4 to 1.5 W/m.K for cement concrete (1200-2100 kg/m^3) [18],[22],[22]. This suggests that cement/ binder may not be the main factor affecting the thermal conductivity of optimised CEBs. The thermal conductivity of CEBs is influenced by the stabilization through the evolution of the resulting bulk density: the denser optimised CEBs, the higher the thermal conductivity.

5. Bulk density and compressive strength of CEBs

[1] stated that "*according to the results exposed, Fig. 15 shows the relationship between the dry bulk density and the compressive strength found. The R^2 value describes a good correlation in the fibre-optimised CEBs case (0.874), whereas it describes a weak correlation in the non-optimised ones (0.398)*". Firstly, it is uncommon for CEBs to reach the value of dry bulk density as high as 2800 kg/m^3, especially when optimised with fibers. Figure 2a shows that the dry bulk density can barely reach 2300 kg/m^3 [12][13][15][16][23][24], even after hyper compaction at pressure of 25-100 MPa [24]. Moreover, the value of the bulk density decreases with the addition of fibers [25] and/or with the increase of OMC for the production of CEBs [11].

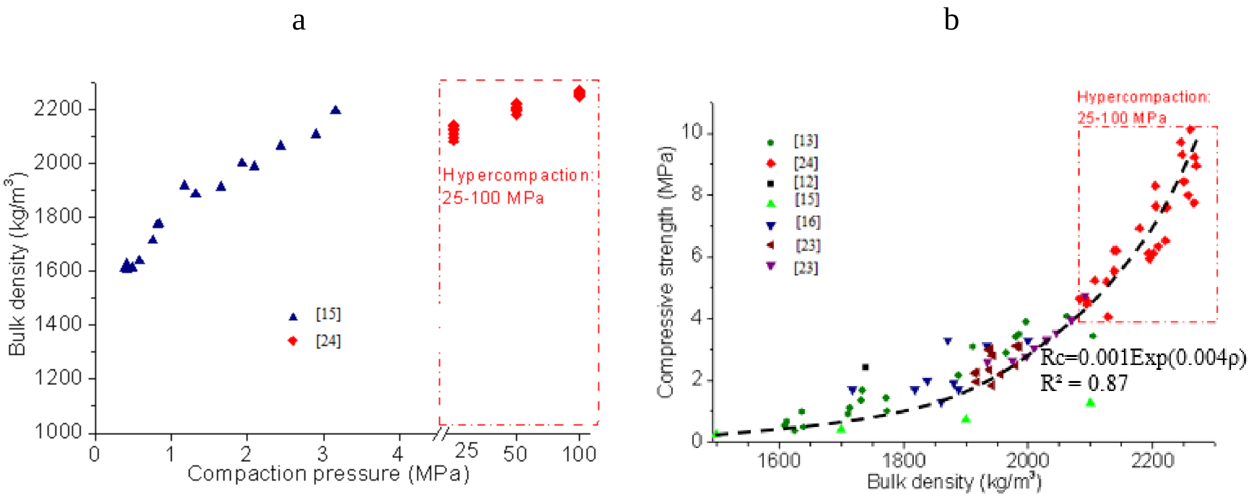

Figure 2. Evolution of a) the bulk density with compaction pressure, b) the dry compressive strength (Rc) with bulk density (ρ) of non-optimised CEBs

Secondly, the trend of the compressive strength with the bulk density is not linear, as simplified in the review [1]. Figure 2b shows that the dry compressive strength (Rc) of non-optimised CEBs increases quasi-exponentially with the bulk density (ρ) in the range of 1600-2300 kg/m^3. More specifically, the compressive strength increased in the range of 0.5 to 4 MPa for the bulk density in the range of 1600-2100 kg/m^3 (for CEBs produced at low to high compaction pressure <10 MPa), and 4 to 10 MPa for the bulk density of 2100-2300 kg/m^3 from the hypercompaction (25-100 MPa). Therefore, it would not be appropriate to consider a linear correlation between the dry compressive strength and bulk density.

Moreover, [1] observed that "*among the studies analysed, most of the blocks are simply dried in the open air, and the best performance is recorded after at least 28 days*". CEBs, especially optimised with binders, should not be simply dried in open air. They should be correctly cured in humid conditions, usually covered in impermeable bags, in order to prevent them from drying too quickly and losing the moisture (of production) necessary for the chemical interaction, such as the reaction between the earth and binders, to take place [7]. Otherwise, the optimised CEBs would dry before maturation and have even poorer performance than non-optimised CEBs.

6. Erosion resistance

[1] stated that "*the erosion phenomenon appears when blocks are freely exposed to the weather. Generally, it is assessed by the authors through the water spray test or by the accelerated erosion test. The material is considered erosive (Class 3) when the pit depth is between 5 and 10 mm, and very erosive (Class 4) when the pit depth is between 10 and 15 mm. Over 15 mm (Class 5), the material fails the test*". Firstly, the author should have provided the reference, standard or any other scientific literature, that prescribed these values of the erosion depth and classification of CEB. In fact, these criteria seem more like those applied in a drip erosion test rather than a spray test. The drip erosion test is recommended for soft earth-based materials such as adobe [12]. For CEBs, it is more appropriate to consider the spray erosion test [12].

Secondly, a recent study has challenged the approach of assessing the erosion resistance of CEB only based on the depth of the erosion pit [27]. The study showed that this approach tends to underestimate the erosion resistance of the CEBs. There was risk of testing localized weak spots on the surface of CEB, which resulted in deeper erosion pit and keeping the rest of the surface with little or no indication of erosion. [27] rather proposed to couple the assessment of the depth of the erosion pit with the fraction of eroded area with respect to the total area exposed to the erosion test. However, more studies are still required for a better interpretation of the latter approaches.

7. Conclusion

The present discussion argues on five points, in a perspective of complementing the interesting insights of [1].

The selection of earth for the production of optimised CEBs should take into consideration its reactivity in addition to the parameters of texture and plasticity. In fact, the particle sized distribution and plasticity of earthen materials are important parameters to be considered for the production of dense (optimum granular distribution of coarse particles) and stable (cohesive fine particles) CEBs. However, these parameters are not enough when looking for improving the performances of mechanical and durability resistance of CEBs by stabilization with chemical binders. Therefore, the reactivity of earth with those binder should be assessed for better selection of earth to produce optimised CEBs.

The above also should go with the considerations of the water demand of binders, in addition to that of earthen materials, to produce optimised CEBs. Otherwise, it may lead to poorer performances of optimesed CEBs than non-optimised CEBs.

The compilation of data from various studies does not clearly show a common correlation between the thermal conductivity and density of CEBs, as was claimed [1]. The data only showed that, for a specific study with a particular earthen material, production and testing procedure, the thermal conductivity tends to increase with the bulk density. However, it can be generally admitted that the thermal conductivity of CEBs remained lower than that of concrete of similar bulk density.

The compilation of data from various studies do show a correlation between the compressive strength and bulk density of CEBs. However, this correlation can be better approached by an exponential law rather than the linear law as it was claimed by [1].

The assessment of the erosion resistance of CEBs should take into consideration the percentage of eroded area, with respect to the total area exposed to the erosion test, in addition to the depth of erosion pit. The mere consideration of the depth of erosion pit tends to underestimation the erosion resistance of CEBs, as it presents the risk of testing localized weak points resulting in deeper erosion pit.

8. Conflict of interest

No conflicts of interest are present.

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