Calcium Carbide Residue and Rice Husk Ash for improving the Compressive Strength of Compressed Earth Blocks

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ABSTRACT

Earth stabilization, using two by-products available in Burkina Faso: Calcium Carbide Residue (CCR) and Rice Husk Ash (RHA), improved the performance of compressed earth blocks (CEBs). The effect of adding CCR or CCR: RHA (in various ratios) to the clayey earth was investigated. CEBs were molded by manually compressing moisturized mixtures of earthen materials and 0-15 % CCR or CCR: RHA (various ratios) with respect to the weight of earthen material. The results showed that, with 15 % CCR: RHA in 7: 3 ratio, the compressive strength of CEBs (6.6 MPa) is three times that of the CEBs containing 15 % CCR alone (2.2 MPa). This improvement was related to the pozzolanic reaction between CCR, clay and RHA. These CEBs comply with the requirement for wall construction of two-storey housing.

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Introduction

Depending on the quality of the available raw earth and required performance, stabilization is often undertaken to enhance the suitability of compressed earth blocks (CEBs). Among many other techniques, the addition of chemical binders such as cement, lime, pozzolan and geopolymers can be successfully performed [1-5]. Cement hydration results in formation of calcium silicate hydrates (CSH) and eventually calcium aluminate hydrates (CAH) responsible for binding the earth particles into the matrix and improve the performance of CEBs. Lime reacts with silica and alumina from the earth and pozzolan eventually for developing, with time, the cementitious products [1-4].

By-product such as calcium carbide residue (CCR) can potentially be used for stabilization of geotechnical soil [6]. The CCR is a white greyish by-product containing up to 90 % hydrated lime ($Ca(OH)_2$). Equation 1 shows its formation from the hydrolysis of calcium carbide (CaC_2) during acetylene gas production [7]. Rice husk ash (RHA), another by-product, was reported to have pozzolanic activity in cement and concrete applications [8]. When RHA is formed in controlled condition of temperature (400-700°C), time (1-6 hours) and environment (oxidizing); it can contain up to 80 % of reactive silica [9].

$$CaC_2^{(s)} + 2H_2O^{(l)} \rightarrow C_2H_2^{(g)} + Ca(OH)_2^{(aq.)} + 64kcal \qquad (1)$$

Clearly, the application of CCR was mainly limited to the stabilization of geotechnical soil and that of RHA to cement and concrete. Additionally, little knowledge is available about CCR and RHA found in Burkina Faso and their potential applications. In this study, the characteristics and possibility to use the CCR and RHA for stabilizing CEBs were investigated. The experiments aimed to produce CEBs for load bearing in walls of two-storey housing. A pozzolanic reaction was expected from clay-CCR and CCR-RHA interactions. This interaction was evaluated based on compressive strength of CEBs with various contents of CCR or CCR: RHA.

Experimental methods

Raw materials

The raw earth is reddish clayey soil extracted from Kamboinsé (N12°29.399', W001°32.981', alt. 322 m). Its lumps were softly crushed to free elemental particles. It was sieved to eliminate the oversize on 5 mm for facilitating homogeneous mixing and interaction with the binder. The CCR was collected from Burkina Industrial Gas in Kossodo (N12°25.935', W001°29.374', alt. 301 m). It was crushed using Los Angeles Machine and ball milled until 90 % of particles are finer than 125 µm. The rice husk was collected from Bagre locality (N11°28.43', W00°32.12', alt. 233 m) and incinerated at 400°C for 4 hours in muffle furnace to form grey colored RHA. The RHA was ball milled until 95 % of particles are finer than 80 µm.

Mix design, molding and curing of compressed earth blocks

Firstly, different fractions of CCR (0 to 15 weight %) were added to the earth to evaluate the effect of CCR on CEBs and its optimum compressive strength. Secondly, CCR (10 and 15 %) at different substitution rates with RHA (10 to 40 %), i.e CCR: RHA in 9:1, 8:2, 7:3, 6:4 ratios, was added to the earth in order to understand the impact of the interaction between CCR and RHA. Dry mixing of solid particles (Earth, CCR and/or RHA) was undertaken until occurrence of apparent homogeneity. The appropriate amount of water, equivalent to the optimum water content, was added and the mixing was carried on. For each mix, enough materials were prepared for the molding of at least 3 test specimens (14x14x9.5 cm^3). The specimens were sealed and cured in ambient condition (30 ± 5°C) for 45 days, for the reaction to take place between clay and lime.

Characterization and testing

Physico-chemical and mineral characterization of raw materials

The particle size distribution (PSD), Atterberg's limits, and modified proctor test of the earth were determined in accordance with NF P 18-056 [10] and NF P 94-057 [11], NF P 94-051 [12] and NF P 94-093 [13], respectively. The PSD of CCR and RHA was analyzed by laser diffraction using Mastersizer analyser machine equipped with

Mastersizer 2000 V analysis software and liquid dispersant hydro 2000s [14]. The specific surface area was determined according to BET methods by Nitrogen adsorption using micrometrics Gemini V1.01 instrument [15].

The chemical composition was analyzed by means of X-Ray Fluorescence technique using ARL Perform'X Sequential XRF equipment. The mineral composition was analyzed by X-Ray diffraction technique performed using Bruker D8-Advance Eco 1.5 kW diffractometer equipped with copper anticathode (Cu Kα λ= 1.54060 Å, 40 kV, 25mA) and Lynxeye xe detector in coupled 2θ/θ mode. The qualitative and semi-quantitative analyses of the spectra were respectively done using Diffrac.Eva V4.11 and Topas V5 software of the Bruker based on Rietveld refinement method. The mineral composition was further confirmed by mean of thermogravimetric analysis (TGA). The TGA was carried out using automatic Multiple Sample Thermogravimetric Analyzer TGA-2000. The analysis was carried out in 25-1000°C range with heating rate of 5°C.

The reactivity of RHA was determined according to the method proposed by Mehta [16]. About 1g of the powder was boiled in 200 mL of 0.5 M solution of NaOH for 3 min. The amount of the RHA which dissolved is related to the amorphous reactive silica content in the RHA.

Mechanical testing of compressed earth blocks

The compressive strength was tested using hydraulic press equipped with a 300 kN capacity load cell at loading rate of 0.25 kN/s. The test was carried out according to XP P13-901 [17] and calculation in equation 2. Where, R_c is the compressive strength (MPa), F_r is the maximum load to failure (kN), and S is the applied surface area (cm²).

$$R_c = 10 * F_r / S \quad (2)$$

Results and discussion

Physico-chemical and mineral characteristics of raw materials

Earthen material

The particle size distribution (PSD) is presented in Figure 1 a: this is fitting the CRATerre [4] recommended boundaries for lime stabilization for CEBs. The earth has a median diameter (D_{50}) of 30 µm and contains 30 % of clay particles, 59 % of silt and sand, and 11 % of gravel. It has plasticity index of 16 (limit of liquidity of 45), specific density of 2.75 and maximum dry density of 1.76 g/cm^3 at optimum water content of 17.4 %. Its chemical composition revealed mainly silica (51 %), alumina (24 %) and iron (III) oxides (13 %). The XRD spectrum (Figure 2 a) shows that earth contains mainly kaolinite clay, quartz and goethite estimated at 76 %, 11 % and 9 %, respectively. The TGA (Figure 2 b) recorded loss of weight at around 310 °C (250-350 °C) and 549 °C (425-690 °C) corresponding to the dehydration and dehydroxylation of goethite and kaolinite, respectively: the thermal removing of hydroxyl is indeed reported occurring around 290-330 °C and 530-590 °C for goethite and kaolinite, respectively [18].

Calcium carbide residue

The PSD of CCR presented in Figure 1 b shows D_{50} of 20.5 µm and a rather plurimodal PSD around 10-100 µm with 90 % of particles being finer than 125 µm. BET specific surface area and specific density are 14 m²/g and 2.49, respectively. Chemical composition showed the predominance of CaO (67 %) and total loss on ignition (LOI) of 26 %. The mineral composition of CCR (Figure 2 a) revealed the presence of portlandite (43 %). Portlandite ($Ca(OH)_2$) is the one responsible for the lime treatment of clayey soil

[4, 6]. The CCR also contains carbonate minerals such as aragonite (20 %), calcite (16 %) and rapidcreekite (13 %). The TGA curve (Figure 2 b) is characterized by important loss of weight at 512 °C (425-550 °C) and 815 °C (675-875 °C) related to the dehydration of portlandite and decomposition of calcite, respectively, justifying its high LOI. Similar thermal behavior of CCR was previously reported between 400-620 °C and 620-900 °C, respectively [7].

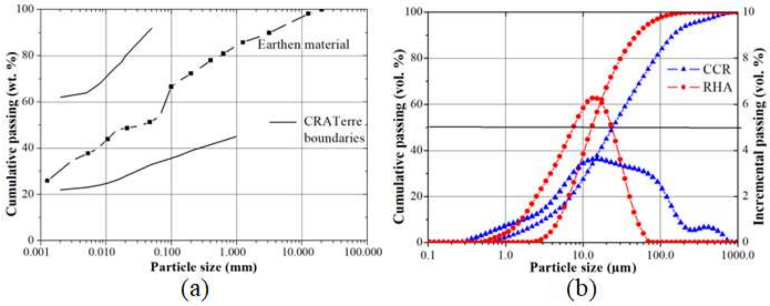

Figure 1. Particle size distribution of materials (a) raw earth and CRATerre recommended boundaries for lime stabilization (b) CCR and RHA after grinding.

Rice husk ash

Figure 1 b shows that RHA is finer than CCR with D_{50} of 11 µm and monomodal PSD concentrated around 10 µm. It has BET surface area of 115 m²/g and specific density of 2.24. The XRD spectrum of RHA shows broad peak around 22° 2θ revealing its amorphous nature with some quartz impurity (Figure 2 a). The chemical composition shows that RHA contains 90 % of total silica. The reactive fraction of silica was found to be 68 % which is in agreement with the observations of Muthadhi [9]. The loss of weight of RHA was mainly observed around 104 °C due to the dehydration of adsorbed water (Figure 2 b).

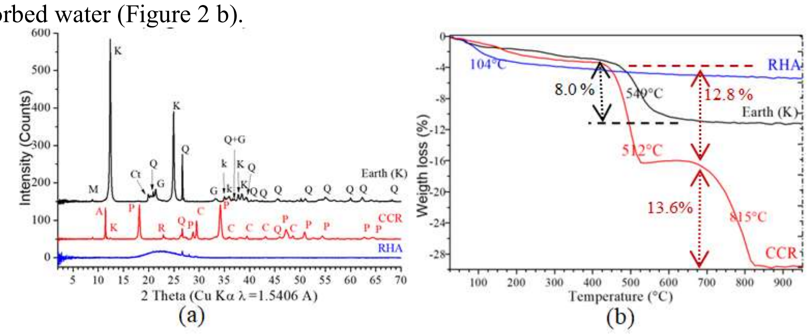

Figure 2. (a) XRD spectra and (b) TGA of raw materials; Ct: Total clay, K=Kaolinite, Q=Quartz, G=Goethite, M=Mica, P=Portlandite, A=Aragonite, C=Calcite, R=Rapidcreekite.

Compressive strength of compressed earth blocks

The addition of CCR to the earth resulted in important improvement of the compressive strength of the CEBs (Figure 3 a). The optimum content of CCR is corresponding to 8 % where the compressive strength almost doubled to 3.4 MPa from

1.9 MPa of the control mix (0 % CCR). This improvement effect was related to the pozzolanic interaction between earth particles, mainly clay sized, with the CCR. Excess CCR (more than 8 %) resulted into detrimental effect due to the lack of effective interaction. Therefore, the zone below 8 % CCR addition can be defined as improvement zone while the one beyond 8 % is a detrimental zone for this particular earthen material.

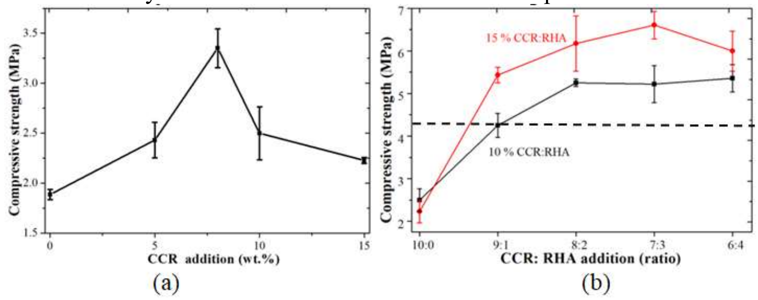

Figure 3. Dry compressive strength of CEBs stabilized with (a) CCR and (b) CCR partially substituted by RHA.

The compressive strength in the detrimental zone was further improved by partial substitution of CCR by RHA (Figure 3 b). In this case, there is potential interaction between RHA and the excess CCR. It was indeed observed that for 10 % CCR, the substitution with 20 % RHA (i.e. 10 % CCR: RHA in 8: 2 ratio) resulted in a compressive strength (5.3 MPa) twice higher than that of CEBs with only 10 % CCR (2.5 MPa). On the other hand, in the case of 15 % CCR, the maximum compressive strength (6.6 MPa) was achieved with 30 % RHA substitution (15 % CCR: RHA in 7: 3) which is three times 2.2 MPa achieved when 15 % CCR was used alone.

In the first stage, a fraction of CCR added to the earth reacts with the clay and produces cementitious compounds which bind earth particles (improvement zone). The excess of unreacted CCR particles remains in between "cemented" zone and reduces the binding efficiency, thus reducing the compressive strength (detrimental zone). The presence of RHA in the mix favors more pozzolanic reaction with CCR and results in more cementitious products which further improves the compressive strength. Similar behavior was reported by Horpibulsuk [6] on the stabilization of silty soil with CCR and fly ash. From this study, the CEBs stabilized by 10 % CCR: RHA in 9:1 ratio exceeded the dry compressive strength of 4 MPa (Figure 3 b). This is the minimum required by the ARS 673: 1996 and ARS 674: 1996 [19] to bear load in two-storey housing.

Conclusions

The compressive strength of CEBs was improved by the addition of CCR or CCR: RHA. This is related to the pozzolanic reaction between CCR with clay and RHA. The following conclusions can be reached from the present investigation:

1. The maximum compressive strength (3.4 MPa) of CEBs was reached with 8 % CCR addition to the earthen material;
2. The compressive strength of CEBs was further improved by partial substitution of CCR with RHA, allowing 6.6 MPa at 15 % CCR: RHA in 7: 3 ratio;

The results from this study imply that CEBs stabilized with 10 % CCR: RHA in 9:1 ratio reached the compressive strength of 4 MPa required for bearing load in two-storey housing. Nevertheless, further studies are needed to investigate the performance of CCR: RHA stabilized CEBs at early age and their long term durability.

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