Effect of production and curing conditions on the performance of stabilized compressed earth blocks: Kaolinite vs quartz-rich earthen material

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Abstract

This study investigated the effect of production and curing parameters on the mechanical performance of compressed earth blocks (CEBs) stabilized with 0-20 wt % CCR (calcium carbide residue). Kaolinite (K) and quartz (Q)-rich earthen materials were mixed with the CCR and used to mould CEBs at optimum moisture content (OMC) and OMC+2 % of the dry mixtures, cured at 20 °C, ambient temperature in the lab (30±5 °C) and 40 °C for 0-90 days. After curing, the reactivity of the materials and compressive strength of dry CEBs were tested. Increasing the moulding moisture from OMC to OMC+2 decreased the compressive strength 0.3 times (4.4 to 3.3 MPa) for the CEBs stabilized with 20 % CCR cured at 30±5 °C for 45 days. Similarly, the compressive strength (4.4 MPa) was reached by CEBs stabilized with 10 and 20 % CCR after 28 and 45 days of curing, respectively. At 40 °C, the compressive strength increased 3.3 times (1.1 to 4.7 MPa with 0 to 20 % CCR) for K-rich and 2.5 times (2 to 7.1 MPa) for Q-rich materials. At 20 °C, the compressive strength increased only 1.3 times (1.1 to 2.5 MPa) for K-rich and barely 0.7 times (2 to 3.4 MPa) for Q-rich materials. These suggest that CCR is useful for stabilization and improving the performances of CEBs in hot regions.

INTRODUCTION

The increasing interests in compressed earth blocks (CEBs) as masonry materials, in the last decades, prove their potential for construction of modern buildings [1-9]. More recently, calcium carbide residue (CCR), a lime-rich by-product, proved to be beneficial stabilizer of CEBs alternative to cement and industrial lime [3,5,8]. CCR owes its benefits from the recycling of a by-product material, otherwise considered as waste [3]. The value of the CCR, as an innovative earth stabilizer instead of Portland cement, is also evidenced by its pozzolanic reaction with clayey earthen materials [8]. Thus, the usage of the CCR would reduce the environmental impacts not only in terms of waste management and CO_2 emissions related to the production of the cement but also the stress to the natural resources. This results in production of stabilized CEBs with improved compressive strength, lower bulk density and better thermal properties than unstabilized CEBs [3,5]. Furthermore, previous studies reported that the pozzolanic reaction between the lime and earthen material highly depends on curing time and temperature as well as the type of materials [10-12]. Moreover, it is commonly suggested that kaolinite clay materials is more sensitive to cement stabilization than montmorillonite. The latter responds more rapidly to the stabilization with lime or mixtures of lime and cement; thus resulting in different development of the performance of the CEBs such as the compressive strength [10-11].

Furthermore, the compressive strength was reported to be affected by the condition of production such the amount of moulding moisture and compaction pressure; the latter being out of the scope of the present study. Additionally, the water demand of the CCR, in addition to that of the earthen material, should be taken into account for production of stabilized CEBs at optimum consistency to limit the detrimental effect on the compressive strength at higher content (>10 %) of the CCR [3]. It was also suggested that the curing process in earth-CCR mixtures be assessed on the basis of the physico-mechanical properties of CEBs [8]. Therefore, the present study investigates the effect of the type of the earthen materials, kaolinite and quartz-rich materials, and curing temperature on the reactivity with the CCR. It also assesses the effect of moulding moisture, curing temperature and time on the compressive strength of the stabilized CEBs.

CHARACTERISTICS OF MATERIALS AND EXPERIMENTAL METHODS

Two different types of earthen materials were studied: kaolinite (K)-rich material extracted from the locality of Kamboinse (12°29024.4800 N; 1°32059.2800 W) and quartz (Q)-rich material from Pabre (12°31023.4600 N; 1°34022.800 W) stabilized with the CCR from Kossodo (12°25.935' N, 001°29.374' W); all available in the vicinity of Ouagadougou, Burkina Faso. The physico-chemical and mineral characteristics of these materials were reported in previous studies [3,12]. The K-rich material is silt-clay of high plasticity (plasticity index, PI: 20 and liquidity limit, LL: 50), containing 20 % clay particles (<0.2 µm), and mainly 60 % kaolinite and only 20 % quartz minerals. The Q-rich material is a clay of medium plasticity (PI: 20, LL: 35) containing 25 % clay particles, and mainly 55 % quartz and 30 % kaolinite minerals [8]. The CCR is finer than 125 µm and contains up to 40 % portlandite ($Ca(OH_2)$) mineral [3].

Mixtures were prepared using the dry earthen materials and 0, 10, and 20 wt% CCR. Mix solutions were prepared by adding 100 mL of deionized water to the mixtures of earthen materials and CCR for assessing their reactivity through the measurement of electrical conductivity over the curing time referring to [8,12]. CEBs (295x140x95 mm^3) were moulded by manual compression of moistened mixtures, made by hand mixing of the addition of optimum moisture content (OMC) and OMC+2 to the mixtures of the earthen materials and CCR, using terstaram press machine (35 bars). The OMC was determined by static compaction, on the mixtures of the earthen materials and CCR referring to [13]; i.e. the OMC linearly increased (OMC=0.21xCCR+17) with the CCR content. The mix solutions and CEBs were curing at 20±2 °C, ambient temperature in the lab (30±5 °C) and 40±2 °C for 0-90 days. Cured CEBs were dried at 40±2 °C until the variation of mass was <0.1 % in 24 h and tested for the compressive strength referring to [14].

RESULTS AND DISCUSSION

Effect of curing temperature on reactivity of the earthen materials with the CCR

Figure 1 presents the evolution of electrical conductivity (EC) of mix solutions made of K-rich or Q-rich materials containing 10 and 20 % CCR cured at 20 and 40 °C, in comparison with the EC of solutions made of 10 and 20 % CCR alone. At 20 °C, the EC of all mix solutions (containing earthen materials and 10 or 20 % CCR) remained quasi-constant over the curing time of 0-45 days (Figure 1a-b). At 40 °C, the EC of mix solution decreased over the curing time compared to the constant EC of solution made of CCR alone (around 6.5 mS/cm for 10 % CCR and 6.7 mS/cm for 20 % CCR) and that of the K-rich and Q-rich earthen materials alone (0.14 mS/cm and 0.06 mS/cm, respectively). The EC recorded significant decrease from about 5 mS/cm at the 7^{th} day to reach the apparent minimum of about 2 mS/cm at 28^{th} day for mix solution containing the earthen materials and 10 % CCR (Figure 1c). For the mix solution containing the earthen materials and higher content of the CCR (20 %), the decrease of the EC occurred from around 5.5 mS/cm at the 14th day to about 2 mS/cm at 45th day (Figure 1d). Although, both earthen materials present quasi-similar evolution of the EC, the EC of the K-rich material tends to be slightly lower than that of the Q-rich material mostly with the 20 % CCR content.

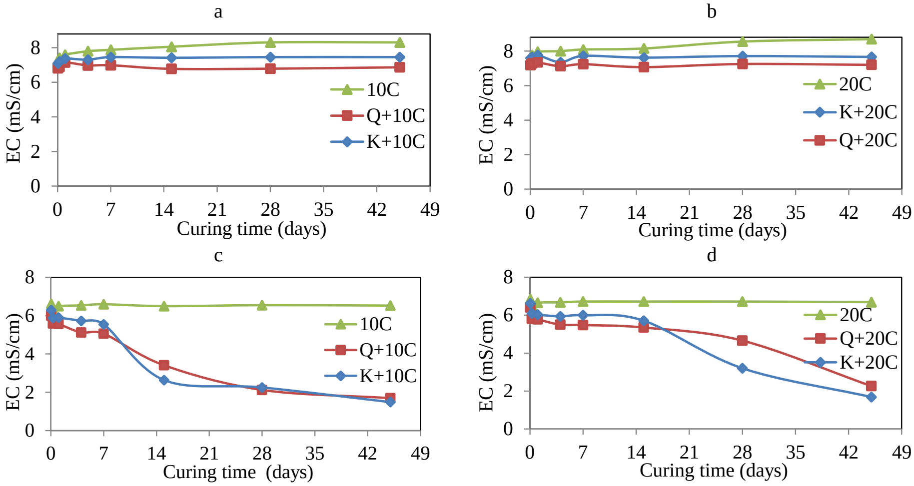

Figure 1. Evolution of the electrical conductivity (EC) of the mix solutions of kaolinite (K) and quartz (Q)-rich earthen materials and 10 % CCR (10C) or 20 % CCR (20C) cured at (a-b) 20 °C and (c-d) 40 °C.

Previously, the evolution electrical conductivity of the mix solutions of earthen materials and CCR was related to the concentration of calcium ions [Ca^{2+}] which initially dissolves from the lime ($Ca(OH)_2$) fraction of the CCR [5]. Throughout the curing, the [Ca^{2+}] decreases following the consumption by the earthen material through the pozzolanic reaction, thus the decrease of the EC. The more rapid the decrease of the EC, the more rapid and effective the reaction. Therefore, the quasi-constant evolution of the EC for the mix cured at 20 °C indicates that only limited reaction occurred at that temperature. By contrast, the significant decrease of the EC at 40 °C indicates that the reaction took place for both earthen materials (K and Q-rich) containing the CCR; with the K-rich recording better reactivity with high content of the CCR (20 %). In fact, similar observation were made in previous study on smectite-rich soil stabilized with industrial lime, which recorded rapid and high reactivity at 50 °C compared to that at 20 °C [10,11].

Effects of moulding and curing conditions on the compressive strength of CEBs

Figure 2 presents the effects of moulding moisture and curing time on the compressive strength of stabilized CEBs produced from the K-rich material cured at lab ambient temperature (30±5 °C). Figure 2a shows that the average compressive strength of CEBs stabilized with CCR decreases with increasing the moulding moisture from OMC to OMC+2. It also shows that the higher the content of the CCR (20 vs 10 % CCR) the more sensible the compressive strength to the moulding moisture. The sensitivity of the CEBs with high (20 %) CCR content to the moistures of production can be related to the initial OMC (17 %) which naturally increased (OMC=0.21xCCR+17) with the CCR content. Therefore; at that CCR content further increase of the OMC to OMC+2 drastically reduced the compressibility and thus the compressive strength of the CEBs. The compressive strength of CCR-stabilized CEBs, produced in the present study using the OMC of the earthen material and CCR, does not decrease beyond 10 % CCR contrary to the previous study [3]. This supports the idea that the moisture demand of the CCR should be taken into account in addition to that of the earthen materials. Thus, following stabilized CEBs were produced using the OMC of the mixtures of the earthen materials and CCR.

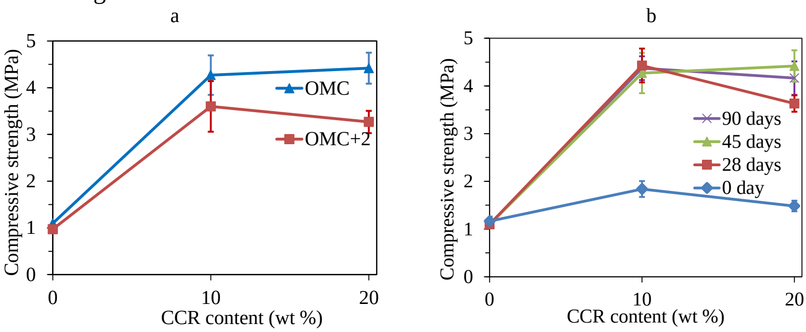

Figure 2. Compressive strength of CEBs produced from kaolinite-rich material stabilized with CCR using (a) OMC vs OMC+2, cured for 45 days; (b) OMC, cured for 0-90 days at room temperature in the lab (30±5 °C).

Figure 2b shows that the average compressive strength of stabilized CEBs produced using the OMC, after 0 day (not cured), evolved from 1.2 MPa (0 % CCR) to 1.8 MPa (10 % CCR) and 1.5 (20 % CCR). This can mainly be related to the physico-mechanical effects of the CCR through the compactness/densification and compressibility of the matrix of the CEBs, recording an optimum with 10 % CCR; beyond which it is detrimental to the effective arrangement and interaction of the particles. Thus, the compressive strength of stabilized CEBs (not cured) is negatively imparted by higher content of the CCR (>10 %). Nevertheless, the compressive strength increased with the curing time, reaching the apparent maximum (4.4 MPa) after 28 and 45 days of curing respectively with 10 and 20 % CCR; corresponding to 1.4 and 2.0 times the compressive strength at 0 day. This can be related to the reactive effect through the pozzolanic reaction of the CCR with the earthen material. It confirms that the more the CCR content, the more the curing time required to reach the optimum maturity at ambient temperature and counteract its detrimental physico-mechanical effects on the compressive strength [3-8].

Figure 3 presents the effect of the curing temperature on the compressive strength. For CEBs cured at 20 °C, the compressive strength increased 1.1 times (1.1-2.3 MPa) and 1.3 times (2-4.7 MPa) respectively for K-rich and Q-rich materials stabilized with 0-10 % CCR. Beyond that, the compressive strength of the K-rich material slightly increased to reach 2.5 MPa, while that of the Q-rich material decreased to 3.4 MPa with 20 % CCR (Figure 3a). For CEBs cured at 40 °C, the compressive strength increased 2.6 times (1.1-3.9 MPa) and only 1.9 times (2-5.7 MPa) respectively for K-rich and Q-rich materials stabilized with 0-10 % CCR. The compressive strength continued to increase beyond 10 % CCR, though at lower rate, respectively reaching 4.7 and 7.1 MPa with 20 % CCR (Figure 3b). The increase of the compressive strength can be partly related to the physical effect, particularly for CEBs cured at 20 °C which did not show much indications of reaction, and mainly the reactivity of the earthen materials with the CCR [3,8,12]. Thus, this confirms that the K-rich material has better reactivity than the Q-rich materials; demonstrated by the continuous improvement of its compressive strength at low and high content of the CCR (10 and 20 %), at low and high temperature (20 and 40 °C).

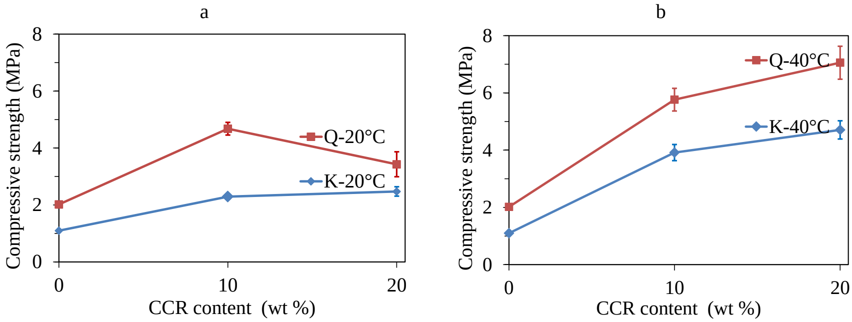

Figure 3. Compressive strength of CEBs produced from kaolinite (K)-rich and quartz (Q)-rich materials stabilized with CCR cured at (a) 20 °C, (b) 40 °C for 45 days.

CONCLUSIONS

The present study investigated the effect of production and curing conditions on the performance of stabilized CEBs. The results showed that the amount of moulding moisture, curing time and temperature affect the performance of CEBs, such that:

1. The maturity of the reaction can be reached in at least 45 days for the K-rich and Q-rich earthen materials containing high content of the CCR (20 %) and 28 days for those containing low content of the CCR (10 %) at high temperature (40 °C); while this reaction is limited at low temperature (20 °C).
2. The compressive strength of stabilized CEBs decreases with increasing the moulding moisture of the mixtures of earthen material and CCR from OMC to OMC+2 and is more sensible at high content of the CCR (20 %).
3. The compressive strength of stabilized CEBs moulded using the OMC and cured at 40 °C continuously increases to reach 4.7 and 7.1 MPa respectively for K-rich and Q-rich materials with 20 % CCR, compared to 2.5 and 3.4 MPa reached at 20 °C.

These results suggest that not only should the reactivity of earthen materials be assessed, but also the effect of production and curing conditions on the performances of stabilized CEBs useful as alternative masonry in modern building construction. They also show the usefulness of stabilization of CEBs with the CCR in the hot regions.

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