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Fired hollow clay bricks manufactured from black cotton soils and natural pozzolans in Kenya

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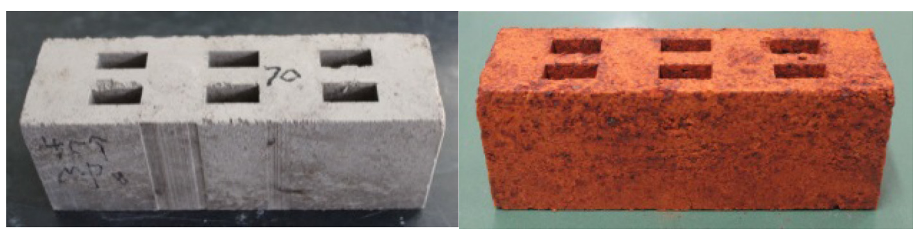
HIGHLIGHTS

- The black cotton soils and volcanic ashes are abundant in Kenya.
- Sintering is an attractive option to allow making use of such soils.
- Optimum parameters were given to get brilliant physical-mechanical properties.
- The mineralogy and firing behavior have been studied via various means.
- Products meet criterion of the first-class bricks based on GB/T 13545-2014.

GRAPHICAL ABSTRACT

Fired hollow clay bricks have been manufactured by firing the black cotton soil and natural volcanic ashes which were both collected from Kenya. Insights on the mineralogy and firing parameters were provided in obtaining brilliant mechanical properties.



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ABSTRACT

The fired hollow clay bricks (FHCBs) have been manufactured by firing a type of highly expansive soils, the black cotton soil (BCS), and natural volcanic ashes (VA), which were both collected from Kenya. Characterizations including the X-ray diffraction, thermogravimetric analyses and electron microscopy have been performed to derive mineralogical transformations in the firing process. Various feedings and firing temperatures have been tried to examine impacts on the physical-mechanical properties (compressive strength, bulk density, linear shrinkage and apparent porosity). Results indicated that the mass ratio of BCS:VA 7:3–8:2 can readily diminish the shrinkage of the FHCB, and the firing temperature (1000–1100 °C) affords the best physical-mechanical performance. The products meet requirements of the first-class FHCBs MU10.0 referring to GB/T 13545-2014. The mineralogical study indicates that clay minerals in BCS undergo decomposition at about 900 °C, and the reaction as well as the phase transformation was proposed as: phyllosilicates + volcanic glass → feldspar → pyroxene → melted substances → vitreous solids, which was a reverse geology evolution of volcanic lava. This research provides a strategy in making use of vast resources BCS in Kenya obtained from municipal constructions.

1. Introduction

Black cotton soil (BCS) is mostly found in mid-Africa, south-Asia, and parts of China [1,2]. This type of soils is mainly composed of clay minerals of smectite group which are highly expansive as exposure to water [3,4]. The swelling property gives rise to serious

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problems in civil engineering on condition that it was used directly for construction, or otherwise the BCS has to be thrown away. A case in point was found in Kenya where the BCS was always stockpiled owning to the fast development of municipal constructions. It is to find out a facile but low-cost strategy to utilize the clay soils. Sintering is an attractive option to allow making use of such soils.

Fired clay bricks are the best known type of bricks and also one of the oldest construction materials [5]. With the development of civilization, great demands are foreseen for the developing countries especially for Kenya as in Africa. However, the clay soils are a type of precious resources. To reduce consumption of clays, the fired hollow clay bricks (FHCBs) more favored due to the less consumption of soils, brilliant strength, and light-weightiness. In this research we proposed a strategy to manufacture FHCBs by using the BCS. This proposal was also based on the abundance in volcanic ashes (VA) which can be obtained in Kenya. However, the knowledge of both BCS and VA in mid-Africa is quite limited, and the mineralogy and firing behaviors remain unknown up to date. Although there were studies on the mineralogy from point view of geological evolution [6], the direct use of BCS as industrial products has not been reported yet [7]. Herein, a detailed study was conducted by means of wet-chemical analysis, mineralogical phase study, thermal measurements, and the optical-/electron-microscopy characterizations. Various feedings (BCS:VA) and fired temperatures (T) were found to have great impacts on the physical and mechanical properties.

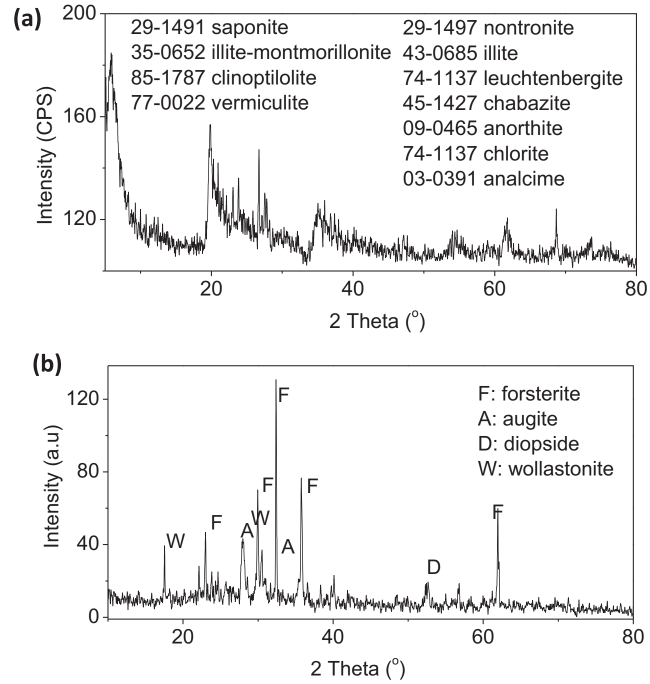

Fig. 1. The XRD profiles of the BCS (a) and VA (b) used in this research.

2. Materials and methods

2.1. Materials and characterizations

The BCS clay was sampled from a site of road-construction in Kenya, which is located at the longitude of 36°31′ E and latitude of 1°35′ S. The volcanic ash was collected from Simba quarry, Kenya. Chemical compositions of both BCS and VA are listed in Table 1. The X-ray diffraction (XRD) patterns of BCS and VA are given as Fig. 1. The major components in the BCS were found as clay minerals including montmorillonite, chlorite, vermiculite and illite, etc. Minor phases were found as zeolites, quartz and feldspar. The crystalline phases were identified as forsterite, augite, diopside and wollastonite in the VA, but the amorphous substances are the main phase.

Characterizations including the XRD and the electronic microscopy observation were described as followed. Powders of BCS and VA (after complete drying at 105 °C) are fixed on the holder of XRD diffractometer (Rigaku D/MAX2500, CuKα radiation). Data were recorded in the 2θ range of 3–80° with a speed of 0.02°/20 s per step. For the electron microscopy characterization, tiny pieces of 0.5–1.0 mm were selected arbitrarily from the air-dried specimens, and were observed under a field emission scanning electron microscopy (FE-SEM, HITACHI SU8020) equipped with 15 kV accelerated voltage.

2.2. Firing procedures

The BCS and VA were sundried, grinded, passed through sieves of 200 meshes, and were blended to obtain homogenous mixes consisting with VA of 0%, 10%, 20%, 30%, 40% and 50% (by weight), respectively. The raw briquettes were prepared at a pressure of 4.0 MPa in a mold. The bricks were burnt in electric furnace (KSL-1500X-L) according to designed heating program as shown in Fig. 2.

2.3. Physical-mechanical properties measurements

The physical-mechanical properties include unconfined compressive strength, linear shrinkage, bulk density, apparent porosity and water absorption. Methods in measurements were conducted according to the Chinese National Standards (GB/T 2524), which are similar to the ASTM C67-14 and C20-00 standard tests [9,10]. For example, the bulk density of the brick in grams per cubic centimeter is the quotient of dry weight (W1) divided by the exterior volume (V). The exterior volume of the sintered products in cubic centimeters was calculated by subtracting the suspended weight (W2) from the saturated weight (W3). The W3 was determined while products were immersed in boiling water for 2 h. The W2 was determined after boiling while the specimens were suspended in water. The water absorption was calculated from the ratio between W3-W1 and W1 [11]. The open porosity expressed as a percentage the relationship between the open pore volume in the sintered products and the exterior volume, calculated from the ratio between W3-W1 and W3-W2. Changes in specimen volume after sintering were to determine the linear shrinkage percentages. The unconfined compressive strength (UCP) was measured using the GB/T 13545-2014 standard [12]. The UCP values were obtained in triplicate using a loading rate of 0.1 MPa/s.

3. Results and discussions

3.1. Physical-mechanical properties

3.1.1. External appearance

Photographs of the raw briquettes and fired FHCBs were presented in Fig. 3. The brick samples were prepared as the half-size of diameters ($240 \times 180 \times 115\ mm^3$) termed as the GB/T2542.

Table 1
Chemical composition of the BCS and the VA of Kenya.[a]

Compositions	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	MnO	P_2O_5	TiO_2
BCS	50.34	16.89	9.07	0.37	0.95	0.065	0.017	0.90
VA	45.72	11.75	1.84	9.00	13.75	0.181	0.50	2.68
Compositions	CaO	K_2O	Na_2O	MgO	Organic	H_2O^+	H_2O^-	LOI[b]
BCS	1.70	1.01	0.76	0.95	1.68	7.93	8.15	18.04
VA	9.09	1.09	2.57	13.75	0.67	0.060	0.19	0.64

[a] The chemical composition was obtained via the method of wet chemical analyses [8].
[b] Loss of ignition.