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Mechanical and hygrothermal properties of compressed stabilized earth bricks (CSEB)

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ABSTRACT

In Africa, compressed stabilized earth bricks are used increasingly in construction. The mechanical, thermal and hygroscopic properties of earth-based building materials available in the African market are not known with accuracy. For this reason, it is often difficult to predict the thermal behavior and the sustainability of buildings made from earth bricks. The work presented in this paper aims at measuring the mechanical, thermal and hygroscopic properties of compressed stabilized earth bricks (CSEB) produced by eight brickworks in Senegal. These properties include compressive strength, thermal conductivity, thermal capacity, and water vapor permeability. The mechanical characterization showed that the compressive strength of CSEB made by these brickworks is insufficient for CSEB to be used in a load-bearing wall according to the African standard ARS 674. The thermal characterization gives an average thermal conductivity of 0.75 W m^{-1} K^{-1} and an average specific heat of 1040 J kg^{-1} K^{-1}, with a Variation Coefficient of 8% and 7%, respectively. The hygroscopic characterizations show a low resistance to water vapor of these bricks. These values are close to the few data existing in the literature on CSEB.

1. Introduction

The energy consumption of residential buildings accounts for about 40% of global energy used in the world [1,2]. Residential buildings are responsible for a large share of greenhouse gas emissions [3]. In Senegal residential buildings represent 49% of total final consumption according to the Energy Information System of SENEGAL. It is therefore necessary to reduce this energy consumption to decrease the impact of buildings on the environment. In doing so several solutions have been implemented. Among them, we can note the improvement of building envelope to better thermal comfort in the buildings. In this context, innovative materials based on earth is used as a substitute for conventional materials, such as concrete. Earth has many advantages. It is available in large quantities. The energy requirement for its extract, transform and produce is low. In [4,5] embodied energy of cement stabilized rammed earth is given. Its good capacity to regulate the indoor humidity [6] and its very high thermal inertia [7] are added to these advantages. Both parameters are an asset to improve thermal comfort in buildings. In this context, the laterite is increasingly used in earth construction. The laterite is available in large quantities in tropical countries, it is rich in aluminum, silica and iron oxides [8]. The content of these chemical substances varies with mineral and chemical composition based on formation [8]. Mineralogical analyses showed that the laterite is composed of kaolinite, hematite, goethite and quartz [9]. The kaolinite is the predominant clay mineral in laterites [10]. Pozzolanic reaction in soils containing kaolinite mixed with cement seems to start at about 1 h after the mixing, but does not modified the soil [10]. Earth construction contains several techniques: wattle and daub cob, rammed earth and earth bricks [11]. The technique of earth bricks is the one used in Senegal. The earth bricks can be compressed or not. To improve water resistance, the earth bricks are often stabilized. The stabilization of earth bricks is necessary in rainy zones.

The mechanical properties of CSEB have been studied by many researchers. State of the art on different procedures (Direct unit strength, RILEM test and Indirect tests) used for measuring compressive strength of CSEB has been done by Morel et al. [12]. They have shown in this review that the value of strength compressive of CSEB differs according the test procedure used. Another work about the compressive and flexural strengths of compressed earth bricks stabilized with cement has been done by Walker [13]. The results show that the strength of CSEB is improved by increasing cement content and impaired by clay content. The compressive strength at different days of curing (7, 14, 21 and 28

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days) of compressed laterite bricks stabilized with cement has been studied by Waziri et al. [14]. The largest value of the compressive strength was obtained at 28 days curing. In their work, Jayasinghe and Mallawaarachchi [15] are interested in the flexural strength of compressed earth bricks stabilized with cement. Their results indicate that the flexural strength of compressed stabilized earth masonry walls can be 0.25 N/mm^2 or above, which can be comparable with conventional masonry, such as burnt clay brickwork. Lasisi and Ogunjide [16] have studied the effect of grain size on the strength characteristics of laterite bricks stabilized with cement. The results show that the increasing of laterite/cement ratio decreases the compressive strength and the increasing of finer grain size increases the compressive strength.

Other studies about mechanical and hygroscopic characterization of CSEB have been done. Reddy [17] in a review affirms that compressive strength of CSEB increases with the increase of density irrespective of cement content and moulding moisture content. Also he affirms that the water absorption of CSEB increases with the increasing of clay content in the blocks. The compressive strength and water absorption of CSEB from laterite soil and clay under different compaction has been done by Abdullah et al. [18]. They found that the increasing of compaction increases the compressive strength and decreases water absorption for both CSEB made from laterite soil and clay. Another work concerning the strength and absorption rate of CSEB under different mixture ratios and degree of compaction has been achieved by Abdullah et al. [19]. They have shown that for all mixtures the increasing of compaction degree increases the compressive strength and decreases rates of absorption of CSEB despite their ages. Raheem et al. [20] have determined the compressive strength and the water absorption of lateritic interlocking blocks stabilized with cement or with lime. The results show that the compressive strength of blocks stabilized with cement is better compared to the compressive strength of blocks stabilized with lime. The water absorption decreases when the percentage of the cement or lime increases. Nagaraj et al. [21] have worked on effects of lime with cement in long-term compressive strength and water absorption of compressed stabilized earth blocks. The authors observed a continuous increase of compressive strength and a continuous decrease water absorption of bricks over time.

Other researches concerning mechanical, thermal and hygroscopic characterization of CSEB have been achieved. Bahar et al. [22] have evaluated the mechanical, thermal and hygroscopic performances of compacted cement-stabilized soil. The experimental results showed that the increase of the cement content increases the compressive strength and reduces water permeability of CSEB. The thermal conductivity of CSEB decreases slightly with increasing of cement content and sand content. The compressive strength, water absorption, thermal conductivity and thermal diffusivity of compressed stabilized laterite bricks has been done by Meukam et al. [23]. They found that the increasing cement content decreases water absorption and increases compressive strength of CSEB. The thermal conductivity increases with water content. The maximum of thermal diffusivity is obtained at 14% water content in the CSEB.

Thermal characterization of CSEB has been done by other researchers. The thermo-physical properties of compressed earth bricks stabilized with cement and those stabilized with lime using different soil types has been done by Adam and Jones [24]. The results give for each type of soil a higher thermal conductivity value for the bricks stabilized with cement. Azakine Sindanne et al. [25] have done a thermophysical characterization of compressed earth bricks stabilized by cement and lime. Their results indicate an increasing of thermal conductivity when percentages of cement and lime increase.

Other works concerning hygroscopic characterization of CSEB has been done. Houngan et al. [26] have studied sorption isotherms of laterite bricks stabilized with cement. Hysteresis of sorption has been observed which loop decreases with increasing temperature. McGregor et al. [27] has calculated the water vapor permeability of compressed earth blocks stabilized with cement and compressed earth blocks stabilized with lime. The results show that stabilization (cement or lime) reduce the water vapor permeability of earth blocks. Cement stabilization reduce vapor permeability more than lime stabilization.

All these works have used bricks manufactured in laboratory. The bricks are manufactured as part of the study. The bricks used by home builders are manufactured by artisanal or industrial brickworks. These brickworks produce a lot of bricks per day for home builders.

According to our review, a few number of characterization studies has been done on bricks produced by artisanal or industrial brickworks. Most of these studies are done on the characterization of bricks produced by industrial brickworks. Cagnon et al. [7] worked on the hygrothermal characterization of five extruded earth bricks produced by five brickworks in France. Their results give very close hygrothermal properties, despite the mineralogical difference of bricks. Maillard and Aubert [28] studied the effect of anisotropy on the hygrothermal properties of five extruded earth bricks manufactured by five industrial brickworks in France. Their results show that the extrusion process affects the distribution of clay layer, which has an impact on the hygrothermal properties of brick. Laaroussi et al. [29] determined the thermal properties of a fired earth brick from a Moroccan industrial brickwork. Their results give an average thermal conductivity of $0.346\ W\ m^{-1}\ K^{-1}$ and an average thermal effusivity of $705\ W\ m^{-2}\ K^{-1}\ s^{1/2}$.

The aim of this work is the characterization of compressed stabilized earth bricks found on the Senegalese market and proposed by different brickworks artisanal. The originality of this work compared to the others mentioned above is that it concerns of CSEB manufactured by artisanal brickworks. This kind of bricks are used increasingly in building construction in West Africa. The artisanal brickworks do not know the precise quantities of materials used in their formulation. The formulations can vary from one producer to another. The mechanical, thermal and hygroscopic properties of CSEB available on the Senegalese market are not known with exactness. For these reasons, it is often difficult to predict the thermal behavior and sustainability of buildings made from these earth bricks. In order to do the bricks characterization, we have chosen eight representative artisanal brickworks in Senegal. In their stock of bricks, we collected six samples from each. These samples are mechanically and thermally characterized. A statistical analysis of the results is then made to obtain the properties that could be used in the analysis of energy performance of buildings made with CSEB

2. Materials and procedures

2.1. Materials

The samples studied were manufactured with laterite, sand and cement. The cement used is Portland CEM-II 32.5 MPa produced by the three cement companies based in Senegal. In this study, the eight artisanal brickworks selected are named, respectively, A, B, C, D, E, F, G and H for anonymity. In the stock of each artisanal brickwork six samples is collected for characterization. The technique of manufacturing bricks is the same for all artisanal brickworks except for C and F. After its extraction, laterite is dried through spreading. The grinding follows, which consists of breaking large pieces of clay. After the grinding, the sieving of laterite is done with a sieve having a diameter of 5–10 mm. Properties of laterite before modification are gives in Table 1. These properties concern the laterite used by artisanal brickwork A. The next step is the manual mixing, which is done to homogenize the mixture of laterite, sand and cement. The mixture is humidified progressively. The wet mixture is then poured into a manual press for compression. When the brick is demoulded, it is placed in a moist cure for 5–14 days, then stored pending use. However, brickworks C and F do not place their bricks in a wet cure after demoulding, instead they are directly exposed to the sun. It should be noted that the artisanal brickworks do not use the same proportions of laterite, sand and cement. The compacting pressure is not mastered as the press is