Research Article

Journal of Materials and Polymer Science

Straw Reinforced Unfired and Fired Clay Bricks for Sustainable Building Construction of Meskine Region (Far- North Cameroon)

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Submitted : 20 Apr 2022 ; Published : 19 May 2022

Citation: Soureiyatou Fadil-Djenabou, Straw reinforced unfired and fired clay bricks for sustainable building construction of Meskine region (Far- North Cameroon). J mate poly sci, 2022; 2(2): 1-7.

Abstract
Clay bricks are the most used building materials due to its great mechanical properties and natural abundance. Therefore, this study is performed to further investigate the mechanical properties of straw reinforced unfired (Ufb) and fired bricks (Fb) as building blocks. In this capstone, bricks with the dimensions 40 x 10 x 20 cm were prepared with addition of increasing amounts of straw (0%, 5%, 10% and 15% in wt.). Height samples were compacted; four of them were dried and for other samples were fired at 1050 °C. All the bricks samples were characterized to determine their technological properties. The results for Ufb indicate that bulk density, flexural strength and compressive strength increased up to 10% of straw in the brick formulations and decreased at 15% of addition. At the same time, linear shrinkage, water absorption and porosity decreased slightly with the addition of straw. Hence clay brick containing 10 %wt. % additives showed the best results, the increase starts to have the reversed effect when its percentage is increased beyond this level. For Fb samples results showed that only the porosity increased with straw addition, values of the other parameters decreased with this addition. The addition of straw reinforces the strength of the unfired bricks and enhances the mechanical properties of the composite up to 10% of addition. However addition of straw just increased the porosity of fired brick. Therefore, using clay with addition to straw will represent a good ecological, low energy waste solution to the construction problems as well as recycling constraints. Moreover, no firing use less energy consumption as well and gives more solids bricks for building construction.

Keywords: Cameroon; Clay materials; Fired bricks; Unfired bricks; Straw;

Introduction
Clay bricks are presently, and have been one of the most common and the most important building materials in the world for a decade. In view of the fact that clay is a natural abundant material that has the potential of establishing good strength properties. Global annual brick production is currently about 1,391 billion and the demand for bricks is continuously increasing (Zhang et al., 2013; Suctu et al., 2015). Due to the scarcity of clay, therefore, innovative approaches to producing clay bricks that are less dependent on virgin sources are highly encouraged from the perspective of protecting the natural resources and sustainable development. Therefore, it is possible to further improve its properties with straw reinforcement, recent research studies are interested on the straw material in addition on clay material for unfired or fired bricks construction (Garas et al., 2010; Lawrence et al., 2013; Konecny et al., 2013; Marwen et al., 2014; Aouba et al., 2016; Ahmad et al., 2017; Robinson et al., 2017). The incorporation of straw as an additive proved to be capable of partially solving the wastage of tons of straw annually, and instead, recycle it by mixing it with clay. The straw used by the environment experts proved that it is the most excellent construction material, as well as energy efficient and even fire-resistant. Some studies on straw bales have been carried for the effect of humidity, moisture content and thermal conductivity (Ashour et al 2010; Maldoushi et al 2011). In addition to that, might be considered any substance that is added to the original clay body without modifying its inherent characteristics. The guiding rule when choosing wastes and by-products must rest on their compatibility with the original (host) raw material. They must not degrade the final product by focusing simply on making it a repository for wastes (Konecny et al., 2013). The most commercialized types of bricks are fired ones, however, they are unrecyclable and less absorbent to air moisture. While unfired bricks save more energy, they seemingly have lower resistance, therefore their

use is not recommended for thin walled earth masonry. This problem can be fixed with the incorporation of materials that can be both organic and inorganic to the brick to enhance its properties with a focus on the compressive strength. Bricks with straw material are lighter than concrete bricks without straw. Thus, this structure is expected to be safer and more suitable for residential buildings located in earthquake-prone areas (Surmani et al., 2018). Clay brick with additional use of straw was found to increase the strength up to 48% from any clay brick without straw (Odeyemi et al., 2017). The use of bricks and straw materials would help to get a better understanding of the construction process using the natural additive. This technique has been used practiced for so many years in the North region of Cameroon especially in rural areas of enhancing the mechanical properties of the bricks naturally. The goal of this study is to use a “straw” as a natural additive to clay to enhance its physical properties in construction practices. This approach is economical, eco-friendly, and sustainable in the long run. All of this by making it an ideal material in rural areas where it’s generally cold and humid. Moreover, the price of the resulting brick should be lower than the commonly used bricks in the market in our days. The result that will allow us to make a definite decision of the optimal percentage of the straw and clay will come after comparison of technological properties of our bricks samples and also to determine the optimal properties obtained between fired and unfired bricks.

Materials and Methods

Study area

The studied area cover 130Km^2 and located in the district of Maroua 1 subdivision (the Far-North region) between latitude 10°32’ to 10°37’ N and longitude 14°10’ to 14°20’ E (fig1).

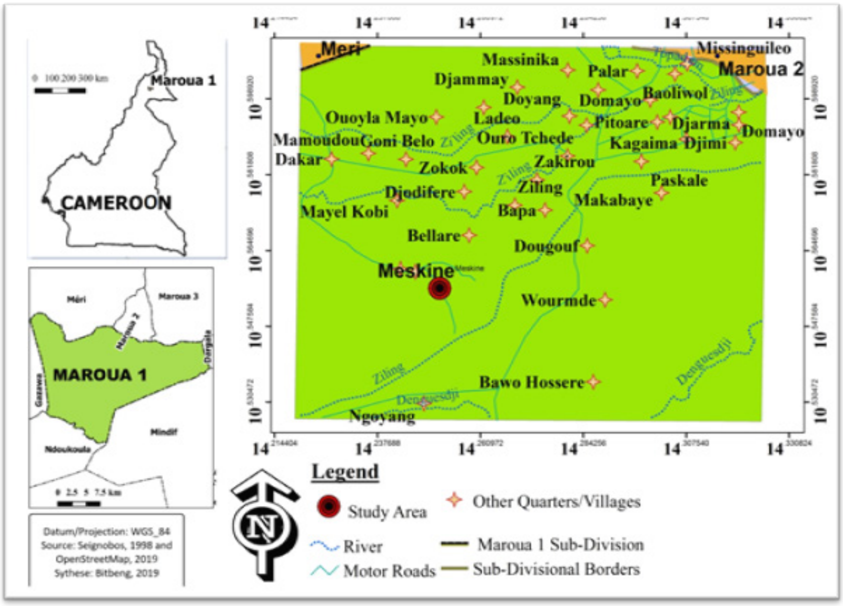

Figure 1: Location of the study area; A) Cameroon; B) Maroua 1 sub division; C) Meskine area

The climate is the Sudano Sahelian type, characterized by a long dry season and a short rainy season. The average temperature is 36.5°C, and the average annual rainfall reaches 73.83 mm. The relief of Meskine is characterized by a set of plains and mountains, and it is little rugged. It is mainly find external karals (320 - 360m) and ancient alluvium. It is also consist of plain surmounted by two mountains: Mount Makabaye and Mount Yamdjidjim (Letouzey, 1980). The cover vegetation is the shrub savanna and the flora is quite diversified with species such as *Acacia seyal, Acacia hockii, Ziziphus mauritiana, Combretum nigricans and Balanites aegyptiaca.* There is also the notorious abundant presence of Neem (Azradirachtaindica) (Seignobos, 1993). A single seasonal watercourse named “Mayo Kaliao” surrounding mountains crosses this region. During the dry season, in the bed of these watercourses, there is a subsurface flow, allowing the water supply of local populations. There are little evolved soils on recent alluvia, coarse sands, and little moist soil (Ségalan, 1967). These soils are very suitable for growing crops like; onions, traditional vegetables and tomatoes. This region is made up of several geological formations of various origins: volcanic, plutonic, metamorphic and sedimentary. In addition to these formations, we also find recent alluvia. They are sands, clayey and silty sands, decantation clays which are products of weathered debris carried off by runoff from Mountains and forming alluvial placers in the Mayo Tsanaga, Kaliao and the Logone River (Detay, 2000). Alluviums cover a large part of the region as well as the study area.

Raw material preparation

The clay materials used in this work were commercial ball clay, which have been used more than 30 years in the production of common bricks and pottery (fig3). Clay particle proportion varies between 23.54 and 58.29%, they are moderate to plastic clay. Meskine ball clay mainly consist of illite (30–50%), kaolinite (10–32%), smectite (2–14%), quartz (3-17%), and few amounts of feldspars, goethite, anatase and gibbsite. The chemical composition of the Meskine ball clays indicates moderate contents in SiO_2 (56-65 wt.%) which are in accordance with the proportion of relic primary silicate as well as secondary siliciclastic minerals. Al_2O_3 contents are rather moderate (15-18 wt.%) and are supported by clay minerals and relic feldspars. Fe_2O_3 contents (av. = 5.24 wt.%) are high, and the alkali ($K_2O + Na_2O$) and alkali earth ($MgO + CaO$) contents are moderate. Other oxides such as MnO, TiO_2 and P_2O_5 are very low and below to the detection limit (Fadil-Djenabou et al; 2022). Straw used in this work was collected from local farms of the studied area. Table 1 give the formulation of the materials for making the test pieces. The clay materials were previously dried in an oven at 105 ° C for 24 hours. Then they are ground in a ball mill. The powder obtained, is sieved at 200 µm. The median of length of the straw particles was about five centimetres. The straw was placed in the sun for a week to reduce the humidity of the latter; it was then placed in an oven to become friable and to take the quantity necessary for the analyzes (fig2).

Figure 2: Straw sample

The mixtures (clay + straw) are weight and homogenized in a mixer (table 1).

Clay%	straw(%)	straw (g)	Clay(g)	Total (g)
100	0	/	3000	3000
95	5	150	2850	3000
90	10	300	2700	3000
85	15	450	2550	3000

Table 1: Formulation for making bricks with straw addition

Bricks with the dimensions 23x11.5x6.5 cm were prepared with addition of increasing amounts of straw (0%, 5%, 10% and 15% in wt.) using a hydraulic laboratory press, for both unfitred and fired bricks tests. Starting from 5%, straw had to be used increasingly thinner while increasing the water content to fully incorporate it onto the brick molds. The mixture was rested for approximately 90 mins before it has been placed in their respective molds. Unfired brick samples were left to dry in room temperature while the other samples were fired at 1050°C. Heating was carried out in a programmable electric oven at a maximum temperature of 1050°C. Then the following technological parameters were evaluated in the two types of bricks (unfired bricks and fired bricks) associated with the straw as well as on a sample without addition in the two types: linear shrinkage, apparent density, absorption of water, porosity, flexural strength and compressive strength for 8 samples.

Figure 3: Meskine Clay sample

Results and discussion

Analysis of technological properties show that with the same proportion of straw linear shrinkage, bulk density, water absorption, flexural strength and compressive strength are increased in the unfired bricks (Table 3). However porosity is increased in the fired bricks (Table 2).

Straw contents (wt %)	0	5	10	15
Linear shrinkage(wt %)	1.68	1.40	1.04	0.82
Bulk density (kgm^{-3})	1.60	1.46	1.18	1.04
Water absorption(wt %)	10.80	12.52	14.23	16.80
Porosity (wt %)	17.50	23.85	33.92	35.23
Flexural strengh (Mpa)	6.23	7.07	6.40	5.22
compressive strengh (Mpa)	34.17	30.50	28.80	17.20

Table 2: Technological properties of fired bricks at 1100°c with straw addition

Straw contents (wt %)	0	5	10	15
Linear shrinkage(wt %)	1.85	1.45	1.06	0.84
Bulk density (kgm-3)	1.66	2.23	2.87	1.68
Water absorption(wt %)	20.40	21.52	21.23	22.86
Porosity(wt %)	19.60	16.40	15.52	13.60
Flexural strengh (Mpa)	7.13	8.40	11.42	7.80
compressive strengh (Mpa)	22.20	27.50	34.80	30.81

Table 3 : Technological properties of unfired bricks with straw addition

There is a significant positive correlation between the increasing amount of straw and the porosity in the fired brick (fig 6). For the same %.wt. of straw porosity is higher in Fb than in Ufb samples. Consequently the pore size distribution of Ufb is more structured and leads to a better compressive strength than fb samples. Porosity is the most important parameter for all the properties of the brick because it influences the mechanical resistance. High porosity permits to save energy because pores in the materials help to decrease thermal conductivity and thus increase its insulating power (Naitali, 2005). The determination of water absorption is a crucial factor which influencing the durability of clay brick, because water can infiltrate bricks and decrease their strength (Babisk et al., 2020; Lawanwadeekul et al., 2020). Water absorption gives information about porosity, low values of water absorption implies good resistance to the natural environment and acceptable permeability of bricks. From the figure 6, it is clear that increasing the rate of straw led to higher water absorption, which can be explained by the difference in the open porosity of all the samples. For comparable %.wt. incorporation and %.wt., water absorption of Ufb was 10% higher than that of Fb (Table 3). The water absorption values of bricks showed a slight decrease with heating. Therefore, according to ASTM C62-13a acceptable values of water absorption may not be higher than 17% for severe weathering resistance bricks, and less than 22% for moderate weathering resistance bricks. Table showed that Kodeck fired bricks with straw addition could be severe weathering resistance brick not and unfired bricks with addition up to 10% are moderate resistance bricks. Linear shrinkage decreases with the straw addition in all the samples (Fb and Ufb), but these values are higher in Ufb than in Fb samples varying from (1.85%) to (0.84%) for Ufb compared to (1.68%) to (0.82%) in Fb (Table2, 3). This could be due to porosity resulting from carbonate decomposition into CO2 and CaO during firing. Since the organic content of straw is much lower than that of clays, and calcium carbonate contained in the straw is eliminated during the thermal process and it leads to an increase of the porosity of the ceramic bodies (Dondi & Fabbri, 2001; Eliche-Quesada, 2017).

Shrinkage also occurs owing to evaporation of the water between clay particles, which causes the particles to move closer together (Quagliarini et al., 2010; Bories et al., 2015; Laborel-Préneron et al., 2017). In addition, firing leads to a low vitrification time, which, consequently, could reduce the shrinkage of fired bricks. Reduction trend of linear shrinkage both in Fb and Ufb with the addition of straw indicates the effective behaviour of straw as a shrinkage barrier (Bal et al., 2012). Results of compressive strength show that it is higher in Fb that in Ufb with 0% of straw addition (Table). The addition of straw with firing reduced the compressive strength of bricks by 5 % compared to that unfired bricks (Table). Moreover, the average decrease in compressive strength for Fb compared to the reference brick bricks was measured to be 30, 28, 17Mpa for the bricks incorporating 5, 10, and 15% of straw addition, respectively. The lowest compressive strength of bricks was obtained for the 15% brick addition, which is about 17Mpa. Reduction of compressive strength in Fb could be linked to the high porosity, which decreases the mechanical resistance (Lingling et al., 2005; Cultrone & Sebastian, 2009, Chen et al., 2011). Increase of compressive strength in Ufb, with the same straw addition is in accordance with studies showing an increase of the compressive strength with the addition of plant aggregates (Laborel-Préneron et al., 2017). Therefore, the compressive strength of all straw addition bricks meets the minimum requirement of 5MPa stipulated in the Australian Standards (ANZBP.2015). Bulk density and flexural strength increased up to 10% of straw addition and then decreased with 15% of straw addition in all samples (Table2, 3). It appears that 10% of straw addition is the maximum for this reinforcement. This result is consistent with the results for porosity and water absorption in Fb (Fig6). Adding straw makes the brick more porous and therefore less dense with firing. This implies that the usage of straw in fired bricks could result in the category of lightweight fired clay products according to EN 12390-7:2009. Values of bulk density less than 2 for Fired bricks is also required for traditional ceramics (Traore et al., 2001).

Figure 4 : fired brick with straw addition

Figure 5 : Unfired brick with straw addition

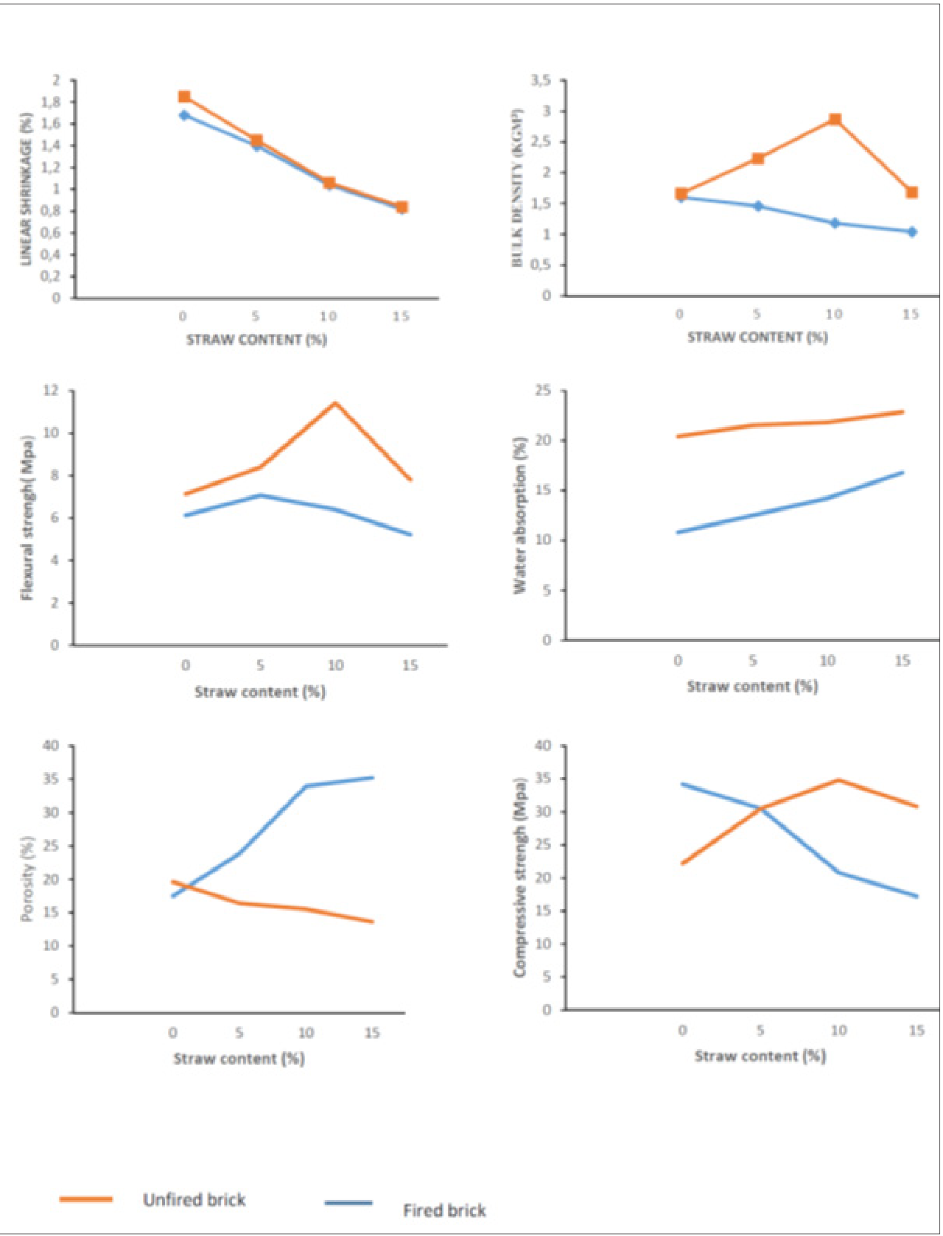

Figure 6 : Technological properties of fired and unfired bricks with straw addition

Conclusion

From the results achieved gotten from this study on the mechanical properties of straw reinforced unfired and fired clay bricks for sustainable building construction, the following conclusions were obtained:

The compressive and flexural strength resistances of the fired bricks reduced as the straw addition level increased, but their porosity increased with these addition.

The sample with 10 wt. % of straw addition showed good potential as ceramic bricks due to the optimize differences in linear shrinkage, water absorption and bulk density.

The development of straw reinforced fired bricks is a promising recycling method for low-cost and light-weight bricks production.

Due to the results on the results obtained for the addition of straw used in this study, the authors recommend the addition of up to 10% of straw addition for unfired bricks, for best-quality bricks.

Acknowledgement

The authors would like to thank the head of department of Life and Earth Science, University of Yaoundé I for providing the research facilities to complete this project, and the team manager of the Cameroon Local Promotion Mission for providing logistic facilities during the fieldwork.

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