The raw earth brick: a building material to meet the needs of local populations

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ABSTRACT: This study tests the ways of improving compressed earth bricks by the addition of sugar cane bagasse, alluvial sand and fine aggregates. The objective is to contribute to the valorization of clay resources, with the aim of developing the production of sustainable, local and energy-saving building materials, particularly in the peri-urban areas of Kinshasa in D.R.Congo. Two raw clays were characterized and then mixed with the different additives to obtain raw earth bricks. Those bricks were then submitted to flexural and compression tests to evaluate their mechanical properties. The addition of 0 to 7.5% bagasse increases the flexural strength from 0.66 to 0.99MPa and the compressive strength from 2.54 to 3.14 MPa. The addition of 0 to 50% sand increases the flexural strength from 0.56 to 0.71 MPa and the compressive strength from 2.28 to 3.09 MPa. The addition of 0 to 35% of fine aggregate does not affect the flexural strength, but increases the compressive strength from 2.28 to 3,10MPa. Stabilization with sugarcane bagasse, sand or aggregates is an interesting prospect to improve by a factor of the order of 1/3 the mechanical properties of raw earth bricks. In addition the mechanical properties are also affected by environmental variation in humidity. The durability of the bricks (i.e., its resistance to water) was therefore evaluated by “the wetting drying test” after an addition of cement. The compressive strength after six cycles of wetting-drying decreases by 25% for the bagasse mixture, 6% for the sand mixture and 2% for the aggregate mixture. Likely an addition of cement allows to significantly increase the durability.

KEYWORDS: Raw earth, valorization, stabilization, durability.

INTRODUCTION

The Kinshasa region and its surroundings are experiencing strong spatial and demographic expansion with, as consequence, the development of peri-urban zones in which the habitat quality is a crucial problem (Lateef et al. 2010). To face this challenge, it is essential to value the use of local and regional natural resources. The use of raw earth in construction is a solution that could meet this demand. This study aims to contribute to the valorization of the clay resources of Kinshasa and its surroundings, with the aim of developing the production of sustainable building materials. The choice of the region is justified by the abundance of clay raw materials and by these very important needs.

Clay is a building material widely used in this region. Its exploitation in construction is generally artisanal. The extracted clays are largely used for the manufacture of wood-fired bricks, with the resulting problem of deforestation (Schure et al. 201 1; Wetshondo 2012). Family societies and craftsmen produce quantities of materials which are not accessible to a large part of the population due to their high prices (Wetshondo 2012). Since the early 1990 and the bankruptcy of the Kinshasa Brickyard, the abandonment of building in clay materials was systematic in Kinshasa. Nearly the whole population turned to a local material: the concrete brick. It is a brick made by manual or mechanical compression by mixing grinding fines of a sandstone rock (the Inkisi sandstone) locally called “dust”, alluvial sands (alluvial deposits of the Congo River or the Mbinza, Kalamu and Ndjili rivers) and cement. Sand is taken directly along the rivers. Three companies located in the neighboring province of Kongo Central provide good quality cement. These concrete bricks of 10, 15 or 20 kilograms cost on average, 1, 1.5 and 2 $ the brick. Despite this high cost for most households, concrete brick architecture remains dominant in Kinshasa.

The use of raw earth should limit the cost of production and produce a resistant construction material. Earth is widely available at low cost. The use of raw earth also reduces environmental impacts because they are renewable, biodegradable, CO_{2}- neutral and energy efficient to produce materials (Baley 2005).

The use of the earth as a building material is an old tradition. Due to his abundance, earthen construction is widespread in the history of this region, especially in rural areas. Most of traditional constructions are made with earth associated with other materials such as plant or mineral additions.

However, the earth has the disadvantage of having a low water resistance (durability) and low load bearing resistance. Different techniques are used in earthen construction to improve its strength (Stulz and Mukerji

1988; Houben and Guillaud 1989). The most used technique is stabilization. Stabilization is a set of physical or chemical processes aimed at irreversibly improving the characteristics of raw earth (Gressillon 1978; Bahar *et al*. 2004). For instance vegetal fibers are used to provide a reinforcement to the earth. They reduce drying cracks and increase tensile strength. They accelerate drying, lighten the material and improve its insulation properties. They contribute to the earth's resistance at the grain scale. The fibers can also be associated with other inorganic stabilizers like sand, cement, lime or bitumen (Houben and Guillaud 1989). The addition of sand and aggregates to the earth modifies its grain size and improve its compactness by making the earth denser (Houben and Guillaud 1989). Cement creates an inert skeleton. It improves the resistance to water by creating bonds between sand and gravel particles. An addition of 5 to 8% of cement or lime generally produces an improvement in the compressive strength and an insensitivity to water (Doat et al. 1979; Rigassi 1995).

In this article, we study the behavior of a stabilized raw clay with the incorporation of sugarcane bagasse, sand and fine aggregates in order to increase their mechanical resistance, water stability and durability of earth bricks. The main objective is the study of the impact of the addition of these stabilizers on the resistance of a raw clay.

The research is based on the traditional technique of Compressed Earth Block (CEB) in order to respect the local habitat and reduce the energy consumption for construction material production. The mechanical properties of the compressed earth bricks will be compared to choose the most appropriate stabilizing agent and optimal proportions between the raw clay and the additives. The improvement of the durability of the selected mixture will be done by adding cement, and then tested by the humidification-drying test or alternating wetting drying cycle.

1.0 MATERIAL PROPERTIES

1.1. Raw clays

The samples were taken in two areas from the Kinshasa province and Mbanza Ngungu (Figure 1).

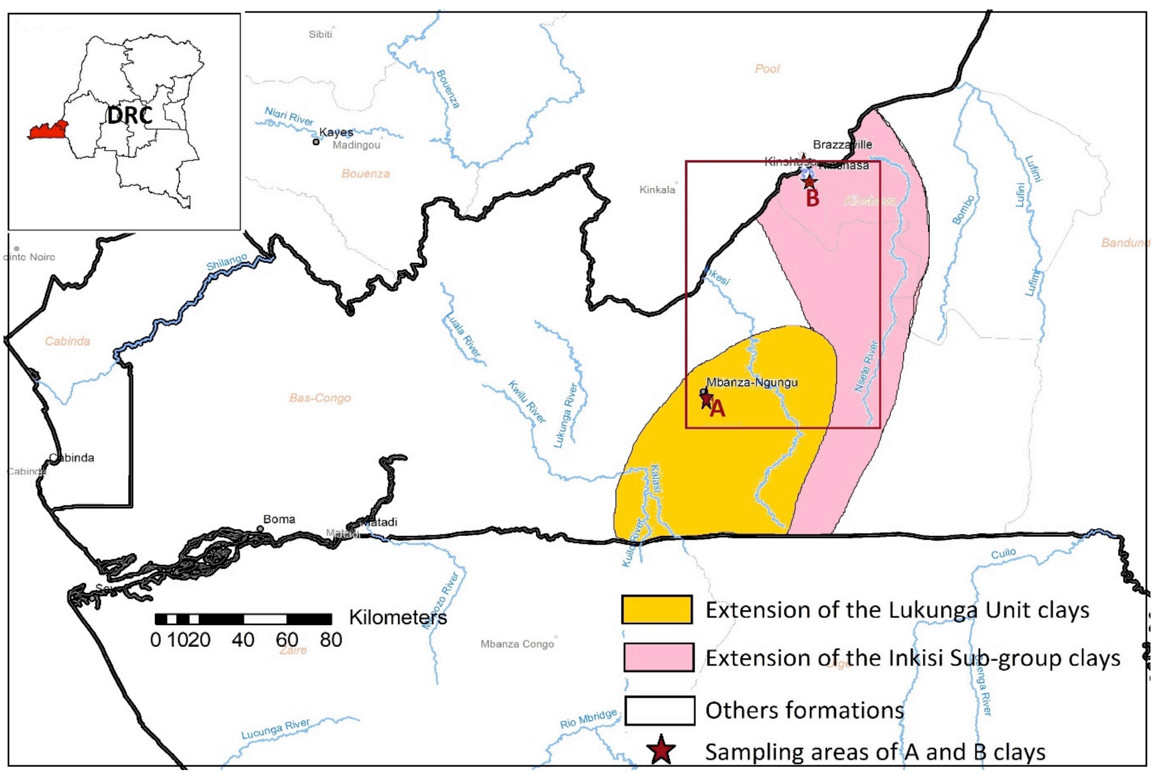

Figure 1: Location map of the study area (red box) showing the sampling zones chosen in the Kinshasa province and Mbanza Ngungu, D.R. Congo. The studied raw clay materials are derived by the weathering alteration of the geological substrate. The colors represent the extension of the two regional geological formations observed in the study area.

The tests focus on two raw clays formed by the alteration of geological formations located in the West Congo Belt. The sample A is formed by the alteration of carbonates rocks from the Lukunga Unit. The sample B is formed by *in situ* alteration of Sandstone from the Inkisi Subgroup. Both clay samples present a yellowish color that is appreciated for the brickyard, widely present in the region.

Each clay sample was stabilized with a stabilizer available in the sampling area where it was taken. Sample A was stabilized with vegetal fibers of sugar cane; sample B was stabilized with sand and aggregate.

1.2. Stabilizers

Bagasse

Sugar cane is an herbaceous tropical grass. Bagasse is the fibrous residue of sugarcane obtained after extraction of the juice. Bagasse is a waste largely present in the southern part of the explored region. It is mainly produced by a local sugar factory located in the region near Mbanza Ngungu. It has been used to stabilize the clay sample A.

The average composition of the bagasse is 45% of fibrous fraction, 2 or 3% of insoluble solids (inorganic fractions), 2 or 3% of soluble solids (residual sucrose molecules, not extracted during the process) and 50% of water (ICIDCA 1990). The chemical composition of the insoluble organic solid fibrous material depends on the sugar cane variety. It consists of polymers made by 15 to 35% of lignin, 25 to 35% of hemicellulose and 30 to 50% of cellulose (ICIDCA 1990; Cuba9 1990; Dinu 2006; Berndt and Hodzic 2007).

Sand

The sand used is an alluvial sand taken along the Congo River. Its particle size is presented in Table 1:

Table 1: Granulometric distribution of the Congo River sand.

>650 µm	>500 µm	>300 µm	>250 µm	>150 µm	>75 µm	>63 µm	>53 µm	< 53 µm
0%	4.1 %	19.1 %	32.6 %	76.8 %	93.8 %	95.6 %	97.3 %	2.7 %

Fine aggregate

It is a fine aggregate of the Inkisi sandstone locally called "dust". Its particle size distribution is shown in Table 2.

Table 2: Particle size distribution of fine aggregate.

>4.5mm	>4mm	>2mm	>1mm	>500 µm	>250 µm	>150 µm	>75 µm	>6 3 µm	<53 µm
0%	1%	23.5%	42.4%	59.2%	76.6%	85.4%	95.1%	97, 4 %	1.5%

Cement

There are different types of cement that differ in composition, strength, setting and hardening speed. The cement used in this study is a composite Portland cement EN - 197-1 CEM II 32.5 R.

2.0 RESULTS AND DISCUSSION

2.1. Properties of raw clays

The two clays were characterized by determining their chemical compositions by X-ray Fluorescence (XRF), mineralogical composition by X-Ray Diffraction (XRD), their Atterberg limits and their particle size distribution by laser diffraction. The results are shown in Table 3.

Table 3: Properties of samples A and B.

Properties	A	B
Chemical analysis (%)		
SiO_2	69.18	72.16
TiO_2	1.3	0.79
Al_2O_3	17.5	14.89
Fe_2O_3	3.54	4.03
MnO	0.01	0.01
MgO	0.01	0.19
CaO	0.07	0.03
K_2O	0.59	0.57

P_2O_5	0.05	0
LOI	7.75	7.33
Mineralogy (%)		
Quartz	53	55
Orthoclase	2	1
Goethite	7	11
Magnetite	2	0
Anatase	1	1
Kaolinite	31	28
Illite	4	4
Atterberg limits		
Liquid Limil LL (%)	34	32
Plastic Limit PL (%)	26	22
Plasticity Index PI	8	10
Particle size distribution		
Sand (2 - 0.063 mm) (%)	15	20
Silt (0.063 - 0.002 mm) (%)	75	68
Clay (<0.002 mm) (%)	10	12

The two clays have very similar properties even they derive from the alteration of different geological substrate. (carbonates for sample A, sandstone for sample B).

2.2. Mechanical tests

We performed flexural and compression tests on raw earth mixtures. Sample A was mixed with 1%, 2.5, %; 5% or 7.5% by weight of bagasse. Sample B was stabilized either by sand (with 35 or 50% by weight) or by fine aggregate (with 20 or 35% by weight)

The manufactured test pieces correspond to the standard dimensions for hydraulic mortar tests: 4x4x16 cm³. The test pieces were stored for 28 days in a controlled atmosphere. The room temperature was continuously maintained at 21°C (± 2°C) and the relative humidity at 60% (± 10%). The mechanical properties are estimated by flexural and compression tests on test pieces of 28 days in accordance with standard NF EN 196-1.

The flexural strength is determined by the 3-point bending test. The specimen is loaded at its center by a force centered and supported by two supports spaced 100 mm apart. The flexural strength is then defined at break. The loading speed during the bending test is 300 N/min. After rupture of the test piece by bending, the two pieces are submitted separately to compression. The compressive strength is determined at break. The loading speed during the compression test is 14.4 kN/min. The results obtained are shown in Table 4.

Table 4: Twenty-eight days flexural and compressive strengths on earth-bagasse, earth-sand and earth-agrregate mixtures.

Stabilizers	Flexural strength at 28 days (MPa)	Compressive str ength at 28 days (MPa)
Bagasse		
0%	0.66	2.54
1%	0.84	2.80
2.5%	0.91	2.92
5%	0.93	2.95
7.5%	0.99	3.14
Sand		
0%	0.56	2.28
35%	0.59	2.59
50%	0.71	3.09
Fine aggregate		
0%	0.56	2.28
20%	0.54	2.54
35%	0.56	3.10

Resistance to flexural and compression increases with the addition of bagasse. Flexural strength evolves from 0.66MPa without any additive to 0.99 MPa with 7.5% of vegetal fibers into the mixing. The compressive strength increases from an initial value of 2.54 MPa to 2.80 to 3.14 MPa with an addition of vegetal fiber ranging from 1 to 7.5%. The flexural strength also increases with the addition of sand from 0.56 to 0.71MPa for a 50 % weight mixture. The compressive strength from 2.28 with no sand to 3.09 MPa with 50 wt. % of sand. The addition of aggregate has little effect on the measured flexural strength. However, the compressive strength increases significantly, from 2.28 to 3.10 MPa with an addition of 35 wt. % of aggregate to the raw clay. For all the additives, the best mechanical results are obtained with the highest amount of vegetal (7.5%) or mineral additives (50% sand or 35% aggregates) to the raw clays.

Depending on the standard used and the country of reference, the compressive strength required for BTC differs, ranging from 1.5 to 3.5 MPa (Figure 2). The tested compressed raw clays display compressive strength values higher than 2.2: those values overpass the minimum requirements, except for the New Zeland standard (NZS). The different additives allow to improve their compressive strength above 3 MPa but still lower than the minimum requirement of 3.5 MPa for NZS standards.

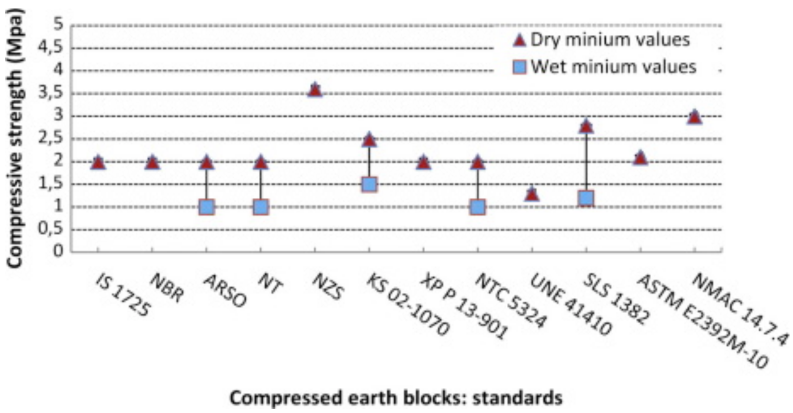

Figure 2: CEB minimum values of dry and wet compressive strength according to different standards: IS 1725 (India), NBR (Brazil), ARSO (Africa), NT (Tunisia), NZS (New Zealand), KS 02-1070 (Kenya), XP P13- 901 (France), NTC 5324 (Colombia), UNE 41410 (Spain), SLS 1382 (Sri Lanka), ASTM E2392M-10 (America), NMAC 147.4 (New Mexico). Source: (Jaime et al. 2012).

Flexural strength is less important than compressive strength in construction. Indeed raw earth constructions are generally dimensioned so that the material is only stressed in compression (Moevus et al. 2012). Therefore there are few requirements concerning the flexural strength of raw earth: it ranges from 0.1 to 0.5 MPa in the few available studies (Moevus et al. 2012). For instance, the New Zealand standard NZS 4298: 1998 recommends a minimum flexural strength of 0.25 MPa (Moevus et al. 2012). The tested compressed earth bricks all reach this minimum value.

2.3. Durability tests

The main disadvantage of the earth construction is its lower resistance to the action of water. To overcome this, we tested the addition of 6% cement on the 3 mixtures that gave the mechanical best results (7,5% bagasse, 50% sand and 35% aggregate). The 3 new mixtures were then subjected to a durability test. This was done by the humidification-drying test or alternating wetting drying cycle. The samples are subjected to six cycles of wetting - drying. They are immersed 25 minutes and then dried at 70°C, 40% humidity for 36 hours. At the last cycle, the compressive strengths of the "aged" samples are measured and compared to "healthy" sample. The humidity resistance coefficient (C_{rh}) is defined by the ratio between the compressive strength after 6 alternating wetting-dry cycles (R_{msa}) on the dry compressive strength R_{dry} ($C_{rh} = R_{msa} / R_{dry}$). The results are shown in Table 3.

Table 3: Values of dry compressive strengths (R_{dry}), compressive strength after wetting - drying (R_{msa}) and humidity resistance coefficient (C_{rh}).

	7,5% bagasse	50% sand	35% aggregate
R_{dry} (MPa)	4.73	3.19	3.71
R_{msa} (MPa)	3.54	3.00	3.64
C_{rh}	0.75	0.94	0.98

This test shows that there is an improvement in compressive strength with the addition of 6% cement. However, durability is not sufficiently improved: The treatment with 7.5% bagasse and 6% cement has a very satisfactory dry strength, however the resistance after wetting drying is altered by 25%. The treatment with 35% fine aggregate and 6% cement has satisfactory dry strength. The resistance after wetting drying decreases by 6%, but remains higher than the previous mixture. Finally the treatment with 50% sand and 6% cement give satisfactory dry strength. The resistance decreases by 2% after 6 cycles of wetting drying, but remains higher than the other two mixtures.

CONCLUSION

On average an earth material with a compressive strength of 2 MPa can be used in masonry. But the minimum value of compressive strength desired is 2.5 MPa. For flexural strength the desired value of the earth bricks for use in masonry is 0.4 MPa. We note that the addition of the different stabilizers (bagasse, dust and sand) allows to reach these values. The best values are obtained with the addition of 7.5% bagasse, 35% dust and 50% sand.

Stabilization with vegetal fiber of sugar cane (bagasse), fine aggregate or sand is therefore an interesting prospect. However, it is essential to do other tests of durability on these materials. The compressive strength decreases by 2 to 25% on the mixing containing 6% cement after 6 cycles of wetting drying. An increase of the percentage of added cement above 6% would lead to maintain the compressive strength values after wetting drying.

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