



## **Corn cob influence on unfired earth bricks' properties**

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## RESUME

Building industry is one of the most polluting sectors. This assessment explains the major challenge of developing sustainable building materials. Unfired earth is experiencing renewed interest as a building material due to its low environmental impact and its capacity to regulate humidity inside the building and thus improve building users' comfort. However, few studies deal with earth bricks incorporating plant aggregates in order to lighten and improve some properties of the material. In response to such issues, the Bioterra ANR project aims to develop and to characterize bio-based earth composites. In this paper, the mechanical and hygrothermal properties of earthen bricks with corn cob were investigated. The proportions of corn cob used in the present study were 3% and 6% by weight of the earth. The results showed that the addition of 3% and 6% of corn cob decreased the compressive strength by 20% and 55% respectively. Concerning thermal insulation, the thermal conductivity of the specimens decreased until 55% due to the lightening of the material. However, water vapor permeability was not significantly influenced by the addition of corn cob.

## 1. INTRODUCTION

Earth has been used as a building material for thousands of years, as have wood and stone. Nowadays, around 30% of the population still live in earth shelters (Minke, 2006), especially in developing countries. Some of the main advantages of building with earth are the availability of the material, its low cost, its recyclability and its low requirement in energy for the transformation process (Minke, 2000). For these reasons, earth is increasingly being studied.

Nevertheless, earth material has some weaknesses, such as hygroscopic shrinkage or limited durability to water (Aymerich et al. 2012). Stabilizers, as hydraulic binders or plant fibers, are generally used to reduce the disadvantages of these characteristics (Danso et al. 2015). Fibers and excrement have always been used to improve earth properties (Chazelles et al. 2011) but their use was based only on empirical knowledge and not on scientific investigations. To date, only around twenty studies have dealt with earth bricks where plant aggregates are incorporated into the earth matrix (Danso et al. 2015) but none focus on corn cob incorporated in raw earth.

This study was carried out in the context of the Bioterra project. This ANR collaborative project aims (i) to characterize earth-based products in terms of their mechanical, hygroscopic and thermal properties, (ii) to characterize the proliferation of microorganisms on these products as a function of various environmental parameters and (iii) to propose solutions to limit the proliferation of harmful microorganisms at the surface of bio-based earth products.

This paper presents the results of an experimental study performed on unfired earth materials with a weight content of 0 to 6% of corn cob. Mechanical, hygroscopic and thermal properties were measured to enrich the databases of bio-based earth construction materials.

## **2. MATERIALS AND METHODS**

### **2.1. Materials**

The material studied in this paper is a bio-composite composed by unfired earth and a plant aggregate which is corn cob. Quarry Fines from Washing Aggregate Sludge (FWAS) were used as earth. These fines are composed of calcite (63%), dolomite (3%), kaolinite (11%), quartz (10%), illite (9%) and goethite (3%). FWAS were extremely fines: 99% of the particles were below 80  $\mu\text{m}$  and the average particle size (D50) determined using the pipette analysis was equal to 6.5  $\mu\text{m}$ . Corn cob is the central part of the ear of corn cleared of grain and crushed. The hardest part was studied here. It was determined by image analysis that 90% of the particles have an equivalent area diameter between 2.5 and 6.4 mm with an average of 3.3 mm.

### **2.2. Manufacturing**

Three different mixtures were prepared for the various tests: (i) specimens made with FWAS only and specimens containing (ii) 3% and (iii) 6% of corn cob by weight content, marked CC3 and CC6, respectively. The water content of the mixtures was determined by the Proctor test. The water content was around 14% for FWAS and 16% for CC3 and CC6. To manufacture the specimens, earth and corn cob fractions were poured into a blender and mixed by hand. Then, water was added and the materials were mixed mechanically in the blender until a homogeneous mix was obtained. The raw materials were mixed the day before molding.

Specimens were manufactured by static compression at the Proctor density: cylindrical specimens 5cm in diameter and 5cm high ( $\Phi 5\text{H}5$ ) for compressive strength and water vapor permeability tests and rectangular prisms of 150x150x50 mm<sup>3</sup> for thermal conductivity measurements.

The specimens were first dried at 40°C for 24 hours, then the temperature was increased by 0.1°C/min to 100°C and kept at 100°C until the weight became constant (weight variation less than 0.1% between two weightings 24 hours apart). This rise in temperature was kept slow to keep shrinking homogeneous and to avoid mechanical stresses. They were then stored in a room regulated at 20°C and 50% relative humidity and were tested from the moment when they were in equilibrium with the environment (about one week later).

### **2.3. Mechanical characterization method**

The compressive strength tests on the  $\Phi 5\text{H}5$  specimens were performed using a 100kN capacity hydraulic press. Three specimens of each mixture were tested in two different tests: one test with the specimen in direct contact with the steel plates (generating friction) and the other including a system avoiding friction. In the latter case, a 2-mm-thick piece of Teflon and a thin neoprene piece - with a drop of oil between the layers - were put between the earth specimen and the steel (neoprene in contact with the specimen, and Teflon in contact with the steel). Displacements and loads were measured in each case. The Young modulus of each specimen was then calculated from the linear part of the stress-strain curve.

### **2.4. Thermal characterization method**

Thermal conductivity properties were assessed on three 150x150x50 mm<sup>3</sup> rectangular prisms for each composition. The measurements were carried out with the EP500 guarded hot plate apparatus. Before testing, the specimens were dried at 100°C and placed in a desiccator to cool. They were wrapped in a thin plastic film to avoid any humidity uptake during the measurement, which was performed at 25°C with a difference of temperature of 10K between the two plates. Steady state was assumed to have been reached when the change in conductivity was less than 1% in 60 minutes.

## 2.5. Water vapor permeability characterization method

Measurements were realized on three  $\Phi$ 5H5-specimens for each composition. The wet cup method was assessed according to the French standard NF EN ISO 12572 (AFNOR, 2001). Before testing, specimens were kept at 20°C and 50% of relative humidity. Humidity of the wet cup was regulated at 86% by means of a saline solution of potassium chloride. This cup, with the specimen on its top, was placed in a chamber regulated at 23°C and 50% relative humidity. The difference of humidity created an outgoing flow of water vapor, measured by regular weighing. The specimens were surrounded by an adhesive waterproof aluminum tape on the lateral face. They were then placed on a plastic support so as not to be in contact with the saline solution. The whole setup was finally sealed by a mix of 60% beeswax and 40% paraffin. The water vapor diffusion resistance factor ( $\mu$ ) was determined for the three compositions.

## 3. RESULTATS AND DISCUSSION

### 3.1. Compressive strength

The average of dry density ( $\rho_{dry}$ ), the maximum compressive strength ( $\sigma_c$ ), the average ultimate strain (corresponding to the maximum compressive strength) ( $\epsilon_a$ ), the average compressive strength at 1.5% strain ( $\sigma_{c,1.5\%}$ ) and the average experimental Young modulus ( $E_a$ ) of each typology of specimen and for each testing protocol are reported in Table 1.

Table 1: Measured mechanical properties of the materials

Test	With friction			Reduced friction		
	FWAS	CC3	CC6	FWAS	CC3	CC6
<b>Type</b>						
$\rho_{dry}$ (kg/m <sup>3</sup> )	1995±0	1878±1	1754±13	1982±10	1876±1	1654±53
$\sigma_c$ (MPa)	4.0±0.4	3.2±0.2	1.8±0.6	3.9±0.9	1.3±0.1	0.9±0.1
$\epsilon_a$ (%)	1.3±0.1	2.4±0.2	2.5±0.5	1.0±0.1	1.2±0.1	1.8±0.2
$\sigma_{c,1.5\%}$ (MPa)	4.0±0.4	2.1±0.3	1.3±0.6	3.9±0.9	1.3±0.1	0.9±0.0
$E_a$ (MPa)	439±54	217±45	102±69	564±161	136±40	69±9

Fig. 1 summarizes the compressive strength of the specimens for the various corn cob contents (0%, 3% and 6% by weight) and for both protocols: with friction at the interface between the specimen and the press, and with reduced friction. For each composition, the compressive strength measured in the tests with friction was greater than that in tests with reduced friction, especially for the samples containing corn cob, because of the confinement. The choice of method used significantly affects the strength value, thus it is important to know which one is the more adequate. The compressive strength of the specimen composed of earth alone was higher than that of CC6 and CC3, which is in

accordance with density values of the various specimens. The average strengths (for the procedure with friction) were 4.0MPa for the FWAS, 3.2MPa for CC3 and 1.8MPa for CC6. All the results, excepted the one of CC6 with reduced friction, were above the minimal value of 1.3 MPa specified by the New-Zealand Earth Building standard NZS 4298 (Standards New Zealand, 1998). It is also important to note that the ultimate strain CC3 and CC6 specimens was higher than for FWAS specimens: between 1.2% and 2.4% for CC3 and between 1.8% and 2.5% for S6, whereas it was only between 1% and 1.3% for FWAS. The addition of corn cob increased slightly the ductility of the composite.

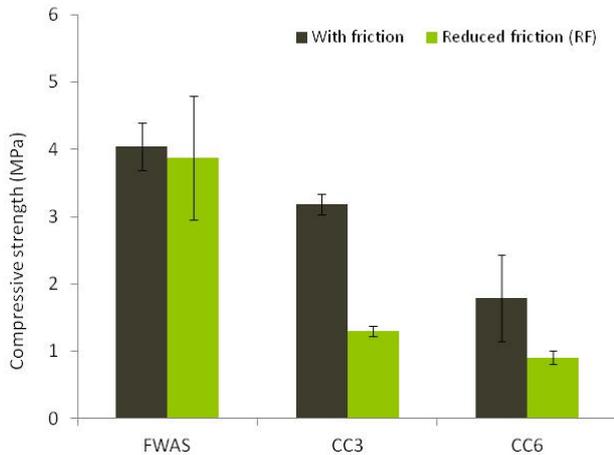


Fig. 1: Average compressive strength

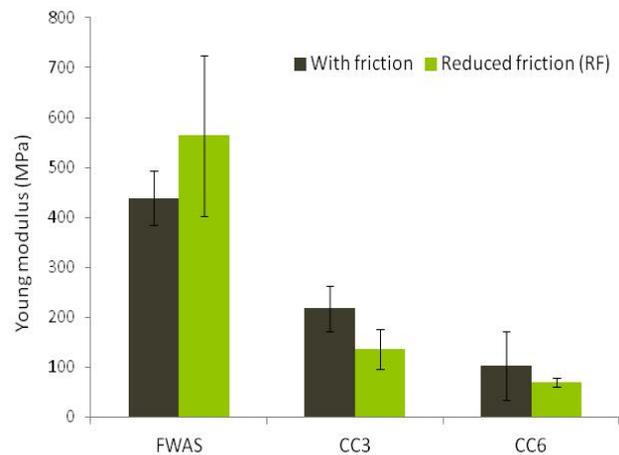


Fig. 2: Young modulus

Young moduli were obtained from compressive strength tests and they are recapitulated in Fig. 2. The most striking result visible in the figure is that the FWAS specimen had the highest value (around 500 MPa). The Young moduli of the specimens containing 3% and 6% of corn cob were far lower (around 220 MPa and 100 MPa respectively). The FWAS specimens presented the highest stiffness of the different types. The increase of corn cob content significantly decreased the Young modulus.

### 3.2. Thermal conductivity

Tests were performed on three specimens for the three compositions. The average values of thermal conductivity obtained (Fig.3) were  $0.57 \pm 0.03 \text{ W.m}^{-1}.\text{K}^{-1}$ ,  $0.35 \pm 0.02 \text{ W.m}^{-1}.\text{K}^{-1}$  and  $0.26 \pm 0.01 \text{ W.m}^{-1}.\text{K}^{-1}$  measured respectively for FWAS, CC3 and CC6 specimens. The results show that the thermal conductivity decreased by about 39% and 55% respectively for the CC3 and CC6 specimens with respect to the FWAS specimens. This decrease of thermal conductivity with an addition of plant aggregates has been widely reported in the literature (Al Rim et al. 1999; Ledhem et al. 2000; Simons et al. 2015). It is linked with the decrease in density of the composite material. The improvement of thermal insulation demonstrates the interest of studying fibered earth bricks.

Fig. 4 represents the thermal conductivity as a function of the dry density of the studied materials (in orange) and other bio-based materials from the literature, in general with an earth matrix. It confirms that thermal conductivity decreases with the dry density. This graph allows the materials of the present study to be compared with others. The values were of the same order of magnitude as those of (Taoukilet al. 2013; Simons et al. 2015) but were significantly lower than those of (Laurent, 1987; Khedariet al. 2005; Liuzziet al. 2013). Even though the results came all from the same type of material, the values were quite scattered. For example, it could be seen on Fig.10 that for a dry density of  $1500 \text{ kg.m}^{-3}$ , the thermal conductivity values were between  $0.25 \text{ W.m}^{-1}.\text{K}^{-1}$  and  $0.61 \text{ W.m}^{-1}.\text{K}^{-1}$ . The measured values of that study were thus situated in the lower part of the referenced thermal conductivities.

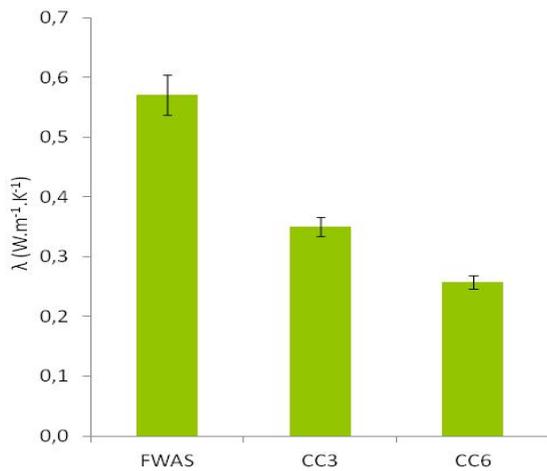


Fig. 3: Thermal conductivity of the materials

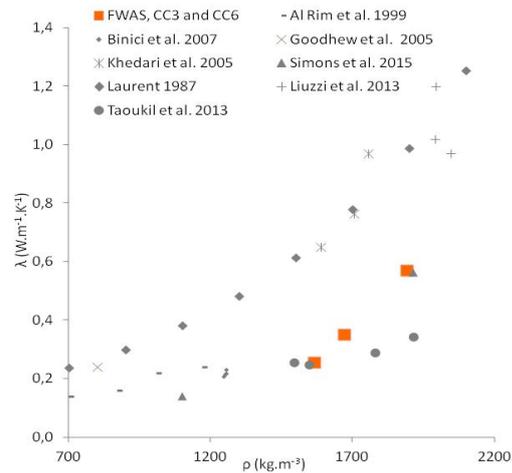


Fig. 4: Experimental and literature values of thermal conductivity

### 3.3. Water vapor permeability

The assemblies were weighed daily over ten days. Using the measurements and the calculation presented in the NF EN ISO 12572 standard, the water vapor diffusion resistance factor ( $\mu$ ) was deduced for each composite specimen. The average values calculated from three specimens are presented in Table 2. All the average factors were very close (4-5), but these results do not bring out the influence of the corn cob. These values were very low, which means that earth is a very permeable material (Cagnonet al. 2014). The results could be compared with reference values of other materials according to the 2012 French Thermal Regulations. For instance, the concrete factor is around 80 and the calcareous stone factor is around 150, which could be related to their compressive strength and their density. The permeability behavior of earth bricks is comparable to that of porous construction materials such as wood concrete or gypsum (lower than 10).

Table 2: Water vapor diffusion resistance factor ( $\mu$ )

	FWAS			CC3			CC6		
$\mu$	4.2	4.8	4.8	4.3	3.8	4.3	5.4	5.8	5.6
$\mu_{\text{moy}}$	4.6±0.3			4.1±0.3			5.6±0.2		

## 4. CONCLUSION

This work investigated the effects of additions of 3% and 6% of corn cob on several properties. The compressive test results showed that a FWAS specimen had the highest strength. Adding corn cob decreased the compressive strength by until 55% for the CC6 specimens. The tests carried out with reduced friction generated lower strength values than the higher friction test. By increasing the corn cob content to 6% by mass, the thermal insulation was increased by 55%. The results confirmed that the thermal conductivity decreased when the material was lightened. These results justify the interest of using light plant aggregates in earth bricks to improve the thermal insulation and thus to make significant savings in the energy used for heating buildings. Corn cob content did not seem to have a significant influence on water vapor permeability, however there remain very permeable to water vapor. As part of the Bioterra project, the effect of the addition of barley straw and hemp hurds had been studied (Simons et al. 2015; Laborel-Préneron et

al. 2015). Furthermore, it would be interesting and necessary to study in greater depth hygroscopic properties of bio-based earth products, especially sorption-desorption, because they can affect the potential growth of microorganisms.

## 5. ACKNOWLEDGEMENT

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## BIBLIOGRPHIE

- AFNOR (2001), Performance hygrothermique des matériaux et produits pour le bâtiment, NF EN ISO 12572.
- Al Rim, K., Ledhem, A., Douzane, O., Dheilily, R.M., and Queneudec, M. (1999), Influence of the proportion of wood on the thermal and mechanical performances of clay-cement-wood composites. *Cement and Concrete Composite*,21: 269–276.
- Aymerich, F., Fenu, L., and Meloni, P. (2012), Effect of reinforcing wool fibres on fracture and energy absorption properties of an earthen material. *Construction and Building Material*,27: 66–72.
- Cagnon, H., Aubert, J.E., Coutand, M., and Magniont, C. (2014), Hygrothermal properties of earth bricks.*Energy and Building*,80: 208–217.
- Chazelles, O. collectif sous la direction de C. de, Klein, A., and Pousthomis, et N. (2011), *Les cultures constructives de la brique de terre crue - Echanges transdisciplinaires sur les constructions en terre crue - 3*. Espérou.
- CSTB, (2012), *Règlementation thermique*, Fascicule 2 : Matériaux.
- Danso, H., Martinson, B., Ali, M., and Mant, C. (2015), Performance characteristics of enhanced oil blocks: a quantitative review. *Building Research and Information*,43: 253–262.
- Khedari, J., Watsanasathaporn, P. and Hirunlabh, J. (2005), Development of fibre-based soil–cement block with low thermal conductivity. *Cement and Concrete Composite*, 27: 111–116.
- Laborel-Préneron, A., Aubert, J.-E., Magniont, C. (2015), Influence de la teneur en chènevotte sur les performances mécaniques et les propriétés hygrothermiques d'un éco-matériau à base de terre crue, *Conférence Internationale Francophone NoMaD*, Douai.
- Laurent, J.-P. (1987), Propriétés thermiques du matériau terre, études et recherches. Cahier 2156.Paris : CSTB, 17p.
- Ledhem, A., Dheilily, R.M., Benmalek, M.L., and Quéneudec, M. (2000), Properties of wood-based composites formulated with aggregate industry waste. *Construction and Building Material*,14: 341–350.
- Liuzzi, S., Hall, M.R., Stefanizzi, P., and Casey, S.P. (2013), Hygrothermal behaviour and relative humidity buffering of unfired and hydrated lime-stabilised clay composites in a Mediterranean climate. *Building and Environment*, 61: 82-92.
- Minke, G. (2006), *Building with Earth: Design and Technology of a Sustainable Architecture*. Birkhauser, Germany.
- NZS 4298 (1998), Materials and Workmanship for Earth Buildings.
- Simons, A., Laborel-Préneron, A., Bertron, A., Aubert, J.-E., Magniont, C., Roux, C., and Roques, C. (2015), Development of bio-based earth products for healthy and sustainable buildings: characterization of microbiological, mechanical and hygrothermal properties. *Matériaux et Techniques*, 103.
- Taoukil, D., El Bouardi, A., Sick, F., Mimet, A., Ezbakhe, H., and Ajzoul, T. (2013), Moisture content influence on the thermal conductivity and diffusivity of wood–concrete composite. *Construction and Building Material*, 48: 104–115.

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