*Eco. Env. & Cons. 28 (3) : 2022; pp. (1262-1274)*
*Copyright@ EM International*
*ISSN 0971–765X*

**DOI No.: http://doi.org/10.53550/EEC.2022.v28i03.024**

# Rush fibers reinforced Adobe for green buildings

**Wassef Ounaies**

***Civil Engineering Department, College of Engineering, Jouf University,***
***P.O.Box 2014, Al-Jouf, Sakaka, Kingdom of Saudia Arabia***

(Received 3 January, 2022; accepted 15 February, 2022)

**ABSTRACT**

In recent years, various local materials on a global scale have been valued and research has multiplied, which has advanced the science of materials. Among these local materials which consume little energy, we cite raw earth which offers the advantages of a fully virtuous life cycle as well as plant fibers which are frequently found in several regions of Tunisian territory. These materials have recently received increased attention as an ecological and green alternative and have aroused the interest of a certain number of scientific works in order to characterize this material and other natural materials available locally with a view to using them in the construction and thermo-acoustic insulation of buildings. Raw earth is one of the modern building materials, although it has been used worldwide for millennia, due to its hygrothermal, acoustic and mechanical performance. It is a natural material available in abundance and easily recyclable. It often does not require any purchase, transport or major transformation. This article aims firstly to present a state of the art of building with raw earth (adobe) combined with plant fibers. The latter used as reinforcement in composite materials have specific competitive mechanical properties compared to those of synthetic fibers (glass, carbon, ...) and are an environmentally friendly alternative to these fibers because of their low cost, low density, biodegradability and availability. Secondly, we present our approach to formulate an earth mortar allowing the making of blocks of adobe, intended for the construction of works such as walls, arches and domes. Adobe is stabilized and reinforced with treated rush fibers.

***Key words:*** *Green building, Raw earth, Plant fiber, Adobe, Rush fiber.*

## Introduction

There is no doubt today that our planet is going through a global warming phase never experienced before, it is manifested by an increase in the rate of the highest temperatures since 10,000 years. Global warming is unequivocal; it has a linear trend estimated at + 0.6 ° C between 1901 and 2000. Temperatures have risen almost everywhere. However, this increase was more sensitive to high latitudes of the Northern Hemisphere.

The construction sector is one area that remains one of the sectors that consume a lot of energy and responsible for the depletion of large amounts of nonrenewable natural resources of our planet. Which generated not only millions of tons of mineral waste released into the environment, but also millions of tons of carbon dioxide emitted into the atmosphere which aggravated the greenhouse effect causing climate change which our sulfur planet (Morel *et al.*, 2001; Binici *et al.*, 2005). Therefore, and as an act of awareness, new generations are demanding healthier building materials and environmentally friendly, which puts the embodied energy in the heart of the debate. This gray energy that comes from the extraction, processing.

Assistant Professor

To deal with this crisis non-renewable energy and the depletion of natural resources need materials that carry a footprint with strong social expectations in terms of eco-housing and green development has become a necessity to reconcile culture and the social, ecological and economics which are the pillars of green development.

Eco-building can be the solution that contributes to significantly reducing the energy footprint of buildings. For these reasons we have opted to promote the use of local materials that we have under our feet to build tomorrow. In recent years, and following the increase in the price of fossil fuels, the decrease in non-renewable resources, the disruption of the climate with an increase in the proportion of greenhouse gases in the atmosphere, and as an act of taking awareness, the Tunisian State represented by the Ministry of Equipment, Housing and Spatial Planning participated in a twinning project with three member states of the European Union (France, Germany, and Portugal) whose objective is to support the Tunisian administration on three fundamental areas of work in the field of eco-construction:

- Strengthen laws and building regulations in favor of green development in the proposed legal texts promoting the development of eco-constructed buildings.
- Develop and promote green building throughout the territory, and for all types of buildings: the awareness centers of influence and target populations with well-based green building, by the organization of seminars addressing all the actors of buildings in the chain from design and construction to provide essential knowledge of supplements in the field of ecological and green construction.
- Strengthen the expertise and know-how of the mastery of public work in this area.

The earthen architecture flood is used quite widely in the dry regions of the world and it is estimated that currently one third of the world population lives in earthen houses based (Binici *et al.*, 2005). Unlike materials and semi-finished products including industrial manufacturing requires a lot of energy; the earth material requires very little energy production. The production of a cubic meter of concrete requires 400 to 800 kWh. The land, natural material, requires only 5 to 10 kWh per cubic meter (Meukam, 2004).

## Raw earth for green construction

### History of the use of raw earth

The land in addition to the stone and wood is one of the oldest building materials in history of mankind. It has been used by civilizations for over ten thousand years (Doat *et al.,* 1991; Piattoni *et al.,* 2011). In fact, archaeological research evidenced that many civilizations such as Persian, Assyrian, Egyptian and Babylonian have used the earth as a building material with plenty to build their habitats that exist to this day (Pacheco-Torgal and Jalali, 2012); Villamizar *et al.,* 2012). These civilizations have built with what they had under the feet to prevent the transportation of raw materials from the mining area to the project area.

Among the most ancient cities that were built based on raw land, we can mention:

- Catalhoyiik in Turkey (Fig. 1a),
- Harappa in Pakistan (Fig. 1b)
- Akhenaton in Egypt (Fig. 1c),
- Chan-Chan in Peru (Fig. 1d)

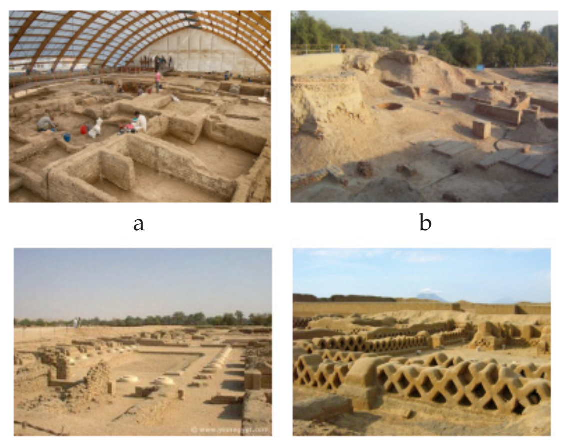


**Fig. 1.** Some constructions in the ground of the oldest civilizations in the world.

### Description of raw earth material

The reasons that pushed us to choose Earth as a matrix of ecological material are essentially:

- His supremacy over all the earth (Pacheco-Torgal, and Jalali, 2012; Binici *et al.,* 2007)
- Durability justified by the existence of several ancient structures built based land (Morel *et al.,* 2001; Doat, 1991);
- Its proper integration within the framework of high environmental quality since the process

uses an abundant material requiring no or very little energy processing or transport (less $CO_2$ emissions into the atmosphere) (Pacheco-Torgal and Jalali, 2012; Piattoni *et al.,* 2011; Villamizar *et al.,* 2012; Binici *et al.,* 2007);
- Its low cost and its impact on the energy used in a building (Silveira *et al.,* 2012; Houben and Guillaud, 2006);
- Its thermal properties contributing to improved comfort in a house providing excellent thermal inertia and regulating humidity and temperature changes (Binici *et al.,* 2005; Doat, 1991; Binici *et al.,* 2007);
- Its high fire resistance;
- Its good behavior Earthquake if incorporated her wooden or metal frames;
- The improvement of indoor comfort (Doat *et al.,* 1991; Daher, 2015);

But it should be noted however that this construction material is water sensitive and to always take precautions to protect it from high humidity and a long contact time with water, by applying a surface coating or protective construction measures such as sufficient overhang roof and waterproof stone base for example. Today, in contexts and varied territories, this building material is still the most used since a third of the world population lives in earthen habitats (Kianfar and Toufigh, 2016; Fratini, 2011). Modest or monumental, these architectures are present in about 150 countries (Figure 2) and they reflect a quality of everyday life and technical innovations that closely combine the expertise, audacity and art (Doat, 1991; Daher, 2015).

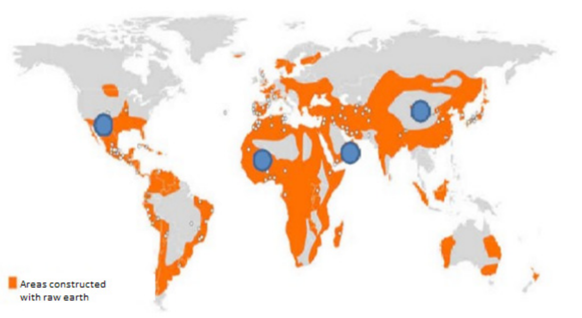


**Fig. 2.** The universality of raw earth as a building material in the world (Doat, 1991).

Due to the environmental problems facing our terrestrial globe, building in raw earth may be one of the alternatives to meet the challenges encountered by the building sector, because today constructions must be healthier, consume little or no energy and less polluting.

**Building with raw earth is**

- Use "natural concrete" which offers a real ecological and economical alternative to contaminating and harmful materials for the environment;
- Develop local resources, both human and natural, by improving living conditions;
- Defend the right to use a natural and ecological building material, plentiful, readily available and accessible, in order to allow the poorest to build their habitat "with what they have under their feet";
- Develop innovation to optimize the material, simplify implementation and produce new architectures.

**Raw earth construction techniques**

If we look at the different buildings constructed from raw earth, we can conclude that there is constructive diversification. Indeed, there are different modes of implementation of the raw earth. Each of these techniques was born from different geographic contexts, particular lifestyles, different customs, and varied climates or depending on the materials available.

The CRATerre team, a *research* laboratory on earthen architecture founded in 1979 and based within the National Superior School of Architecture in Grenoble, France, were able to count twelve earth

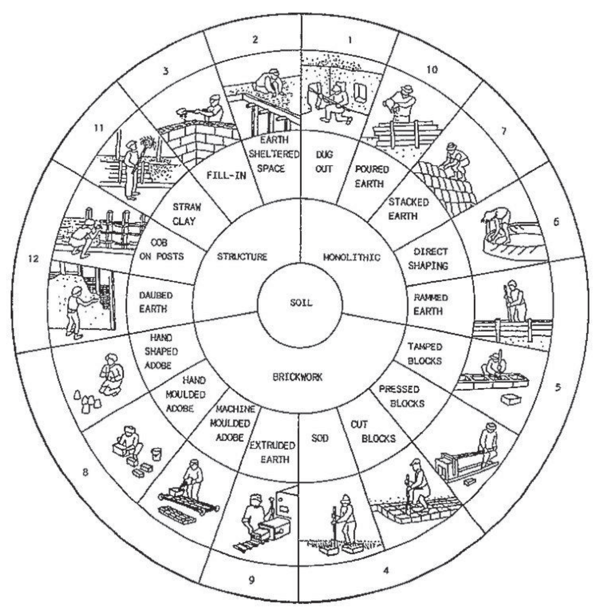


**Fig. 3.** Construction techniques with raw earth (Houben and Guillaud, 2006)

construction techniques as shown in Figure 3 below (Houben and Guillaud, 2006) namely dug earth, covering earth, filling earth, cut earth, compressed earth, shaped earth, cob, stacked earth, adobe, extruded earth, mud (earth + straw) and poured earth.

In our work we are interested in the development of technical terms and specifically adobe manual or mechanical.

**The technique of adobe or earth mortar**

This technique is one of the oldest techniques of earth construction. This technique involves mixing of the earth flood with water and fibers (often straw) sometimes until the mixture reaches a plastic state and then to the molding into wooden or metal molds (Figure 4) and finally to dry in the open air and sunshine.

The earth in this construction technique should contain a given proportion of clay and sand. It should not be very clayey not have too much shrinkage cracks after drying and also should not be too sandy to ensure its cohesion after curing. The addition of fibers can increase the cohesion, decrease cracking and its presence in large amounts makes it possible to improve the heat insulating ability of adobe blocks (Houben and Guillaud, 2006; Kariyawasam and Jayasinghe, 2016).

In Tunisia, in 2012, there was a pilot building with adobe (Figure 4) by GDA association in the Sidi Amor site governorate of Ariana. This pilot project allowed the construction of a building (Figures 4 and 5) totally adobe (except the roof was of timber covered with tiles). The lessons learned as a result of this experience concerned in particular the need to improve the cohesion and strength of the adobe and

**Fig. 4.** Manual manufacturing adobe Process at the site of Sidi Amor – Tunisia

**Fig. 5.** Some achievements with adobe at the site of Sidi Amor - Tunisia

the need to reduce shrinkage cracking.

**Fibers as reinforcement material**

For centuries, natural fibers have been implemented by Man. He mixed with other materials to obtain composites that serve as building materials.
This combination tool as building dated from the 1500s before Christ. Indeed, Mesopotamian and Egyptian built buildings resistant from a mixture of clay and straw. This material was used as reinforcement for composite products comprising ancient pottery and vessels (Toupe, 2015).

**Classification of fibers**

Nowadays, the plant fibers are increasingly answered because they are characterized by good mechanical strength, light weight, low cost and biodegradability. Their use is now in strong challenges in sectors such as the transportation, construction, agriculture, plastics and food, sports, aeronautics, electronics and medicine (Dallel, 2012; Trimeche, 2016). The choice of categories of fibers was also increasingly diverse, for example, flax, hemp, kenaf, palm oil and alfa. Indeed, the main challenge in this area of study is that the use of these materials meet the need for high quality performance on new applications and a production cost moderate to consumers (Toupe, 2015).

In the building sector, natural plant fibers are used in many cases, for example, the use of concrete in hemp insulation and implementation of roofs and insulating tiles or mounting walls. Wool hemp from the crushed hemp stalks replaced glass wool. These natural insulators are characterized by thermo-acoustic performance, regulation ability hygrometric and low gray energy during their production. For some building materials, natural fibers, such as flax or hemp can be used as PVC type polymer reinforcement, PE or PP instead of synthetic fibers, such as, glass, Kevlar or carbon.

These strengths are the attention paid to plant natural fibers is growing in momentum.

We distinguish two main types of fibers, the natural and those of chemical origin as shown in Figure 6.

**Natural fibers**

The use of these fibers has become increasingly varied seen the benefits listed in Table 1 below. They are used to manufacture composite materials to use them later in various fields namely textiles, paper,

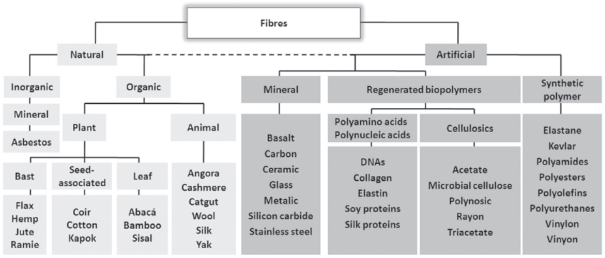


**Fig. 6.** Classification of fibers

etc. which are made from natural fibers, such as esparto, sugar, cane, bagasse, hemp and coconut fiber (Dallel, 2012).

In this family of fibers include plant fibers that are classified according to the organ from which they originate (Figure 6), animal fibers that come from either animal hair as the case of sheep wool, or by secretion and one speaks in this case of silk or spider son, and finally the mineral fibers, where the only natural mineral fiber is asbestos which is characterized by its resistance to heat, fire, chemical attack and by its absorbency, but it has carcinogenic risk, for this reason, its use was banned (Taâllah, 2014).

### Artificial fibers

The latter includes synthetic polymeric bres and regenerated biopolymers. The notion of man-made bre production was mooted in 1664, when Hooke rst examined the structure of natural silkworm bres at the microscopic level and envisaged the possibility of articial silk.

### Structure of plant fibers

Plant cells have two types of cell wall, primary cell wall and secondary cell wall, based on their biosynthetic composition and cellular location (Figure 7).

### Chemical composition of plant fibers

Plant biomass consists of many macromolecules as

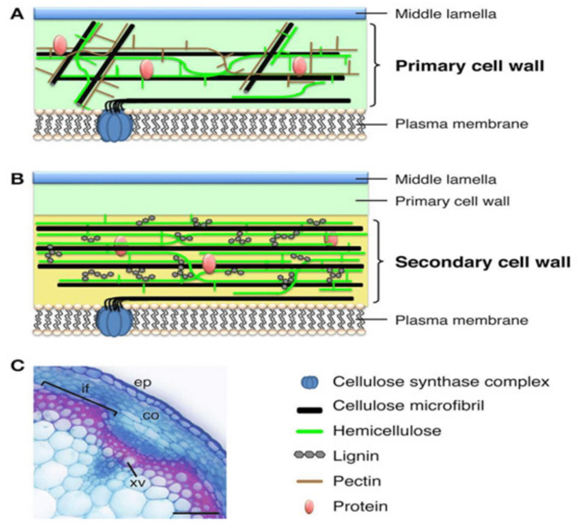


**Fig. 7.** Plant cell walls. (A) Model of the primary cell wall. Cellulose microfibrils in the primary cell wall are relatively short and thin, compared with those in the secondary cell wall, and hemicellulose in the primary cell wall is composed of xyloglucan. The primary cell wall is rich in pectin. (B) Model of the secondary cell wall, which is deposited between the primary cell wall and the plasma membrane. The secondary cell wall mainly contains relatively long and thick cellulose microfibrils, hemicellulosic xylan, and lignin. (C) Cross section of an Arabidopsis inflorescence stem stained with Safranin, which stains lignin red, and Astra blue. co, cortex; ep, epidermis; if, interfascicular fiber; xv, xylem vessel. Bar = 50 μm. (Nakano, 2015).

shown in Figure 8 and Table 3 closely tied together namely as follows: cellulose, hemicelluloses, pectin and lignin (Fehri, 2015). Table 2 gives the chemical composition and percentage proportions of each substance (cellulose, lignin, hemicelluloses, and ash) of the most plant fibers used in the world (Kozlowski and Wladyka-Przybylak, 2004). The proportion of the main components in a fiber (cellulose, hemicelluloses, and lignin), which defines its

**Table 1.** The most notable advantages of natural fibers

| Economic benefits | Technical advantages | Ecological advantages |
|---|---|---|
| - Low cost of extraction<br>- Energy gain at transformation and treatment. | - Low density<br>- Specific mechanical important properties (strengths and rigidity).<br>- Non-abrasive for tools<br>- High geometric stability of parts produced from these fibers.<br>- Good insulation properties thermal and acoustic | - Biodegradable.<br>- Fully recyclable.<br>- Neutral for the emission of $CO_2$.<br>- Renewable resources.<br>- No residue afterincineration |

physical properties and applications (Müssig and Martens, 2003).

**Table 2.** Chemical composition of some plant fibers Kozlowski and Wladyka-Przybylak, 2004)

| Fibre | Cellulose (%) | Lignin (%) | Hemicellulose (%) | Ash (%) |
|---|---|---|---|---|
| Flax | 64–71 | 2–5 | 18.6–20.6 | 5 |
| Kenaf | 44–57 | 15–19 | 22–23 | 2–5 |
| Sisal | 67.5–78 | 8–11 | 10–24 | 0.6–1 |
| Bamboo | 26–43 | 21–31 | 15–26 | 5–17 |
| Rice | 28–48 | 12–16 | 23–28 | 15–20 |
| Coir | 36–43 | 41–45 | 0.15–0.25 | 2 |
| Deciduous | 38–49 | 23–30 | 19–26 | <1 |
| Coniferous | 40–45 | 26–34 | 7–14 | <1 |
| Cotton | 85–90 | 7–16 | 1–3 | 0.8–2 |

## Cellulose

It is one of the most abundant organic polymers on earth and is the majority component of the cell wall. Cellulose; discovery in 1838 as product isolated by the French chemist Anselme PAYEN which made experiments on various plants with an acid or treatment with ammonia provided that it has the same fibrous material. Then the true molecular formula of the cellulose was determined in 1913 by Willtatter and Zechmeister. From 1926 Staudinger clarified in his research the structure of the polymer (Dallel, 2012; Fehri, 2015).

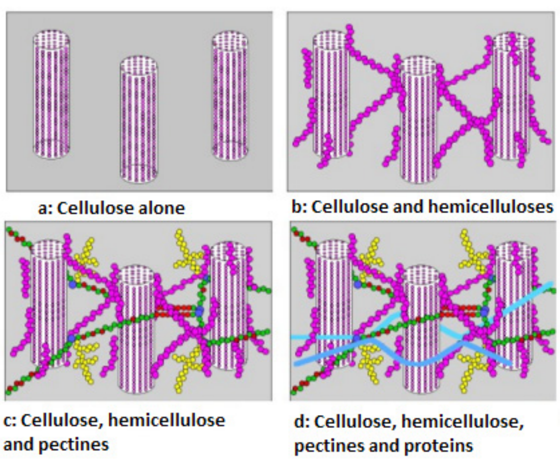


**Fig. 8.** Representation of the various constituents of the cell wall of the plant fiber Ragoubi, (2010).

**Table 3.** The chemical composition of some plant fibers Nair *et al.*, 2013).

| Type of fiber | Cellulose (%) | Lignin (%) | Hemicellulose (%) | Pectin (%) | Ash (%) |
|---|---|---|---|---|---|
| Fiber flax | 71 | 2.2 | 18.6– 20.6 | 2.3 | – |
| Seed flax | 43–47 | 21–23 | 24–26 | – | 5 |
| Kenaf | 31–57 | 15–19 | 21.5–23 | – | 2–5 |
| Jute | 45–71.5 | 12–26 | 13.6–21 | 0.2 | 0.5–2 |
| Hemp | 57–77 | 3.7–13 | 14–22.4 | 0.9 | 0.8 |
| Ramie | 68.6–91 | 0.6–0.7 | 5–16.7 | 1.9 | – |

There are four differentiated polymorphic states (multifaceted) of cellulose by their basic geometry and size from diffraction spectroscopy research X-ray (XRD) as follows:

- Cellulose I: This category Cellulose is cellulose in two forms: Iá and Iâ that coexist in varying proportions. Found mainly Iá phase in the produced cellulose primitive organisms such as algae or bacteria, while the cellulose Iâ is found mainly in cellulose produced by plants such as wood.
- Cellulose II: This cellulose is obtained by a treatment with sodium hydroxide to the original cellulose. An approach developed by Mercer and mercerisation named so in 1844, it consists of swelling in a concentrated alkaline base and washing with water.
- Cellulose III: It is formed when the cellulose I and II are treated with liquid ammonia or tertiary amines.
- Cellulose IV: This cellulose can be likened to a disorderly form of cellulose I according to electron diffraction research. For example it is found in the native state, in the primary walls of cotton and certain fungi.

## Hemicellulose

They look like cellulose. They have as a biological role of strengthening the cell wall by interaction with the cellulose or lignin in some walls. Hemicellulose are distinguished by their solubility in dissolved alkaline solutions. To extract all the hemicellulose, a 10% solution of sodium hydroxide is required. Hemicelluloses establish connections not only with the microphones cellulose fibrils, hydrogen-type (thanks to the similarity between the structure of the cellulose and hemicellulose), but also, they connect the other components, which promotes cohesion of the wall. Finally, they have other functions as food additives (the hydrolysis of hemicellulose leads to sugars, mainly pentose), plastic (films and coatings)

## Lignin

It was in 1819 that this substance was discovered by Braconnot. The latter extracted from wood a compound insoluble in concentrated acid which he named "lignin". The word is of Latin origin: lignum, which means wood. Lignin is the second most abundant compound, after cellulose, in plant species. It is a substance located in the middle lamella and in the secondary walls in which it is incorporated at the end of cell evolution by interpenetration in the micro fibrils of cellulose. Its chemical structure is very heterogeneous and varies according to the species to which it belongs, as well as according to the age of the tissues and climatic conditions. Lignins have a whitish color but they can be colored by oxidizing. In the pulp sector, lignins must be separated from cellulose fibers to obtain good quality paper and make it easier to bleach. However, since lignin is intimately linked to cellulose and hemicelluloses, only severe extraction conditions allow the constituents to be separated.

**Organic substances (or extractable)**

They consist of molecules that form in the porous structure of the timber (eg the lumens of the cells). They can be extracted by solvents such as acetone, water, ethanol, toluene, cyclohexane, dichloromethane. The content and composition of the extractable vary greatly from one plant to another (Fehri, 2015).

**Inorganic substances**

These are substances that develop in the ashes (residues extracted after combustion of organic matter) and are necessary for the evolution of plant species. Their presence in certain subjects is very relative. In the material of wood, they are found only in very small quantities (less than 1% of the entire timber). However, the essential elements are potassium, calcium and magnesium. Sodium and Phosphorus are in less quantity. The presence of Iron, Aluminum, Zinc and Copper is very low because their content does not exceed 50 ppm. Chlorine is also found in trace amounts in herbaceous biomass (Fehri, 2015).

**Related works**

The problem of raw earth construction is that they suffer from a resistance deficit, from cracking systematic due to shrinkage and encounter problems related to their sensitivity to water. Raw earth material can be reinforced by fibers allowing to improve its physico-mechanical performance and its sensitivity towards water, which has gave birth to several earth products: adobe, mud, earth block compressed and others.

Compared to the history of raw earth construction, Adobe technique is a very old technique, it allows to have blocks molded without compaction in terms of the masonry and can be integrated as well in a column-beam structure as a filling material that as the main material in a load-bearing wall.

To obtain better mechanical characteristics of the molded raw earth as to other types of bricks, for reducing its porosity, its dimensional change and improved resistance to erosion from wind and rain (reduce surface abrasion and permeability of the block), more stabilizers binders such as: cement, lime and bitumen can be used alone or in combination with the reinforcement of the earth matrix plant fibers such as: straw, hemp, bamboo, etc. The mechanical behavior of raw earth in general and in particular molded earth is similar to that of concrete. In fact the earth has a good compression behavior which is provided by the inherent strength of the grains that compose it,

The other considerably remarkable problem with earth mortars in general and unstabilized (100% ground) in particular is the shrinkage which is a dimensional variation of the drying material being caused by the evaporation of the water just after the confection. This decrease in volume causes internal stress that can lead to shrinkage cracks. These cracks can change the homogeneity of masonry or structure built based on the land and its sustainability if there is no coating, and also can leak through cracks. This dimensional variation increases with the increase of this clay content in the soil matrix. When the plasticity index exceeds 20, the removal of drying increases rapidly.

The resolution of the mechanical fragility problem and dimensional change during drying may be made by stabilization by various hydraulic binders (cement, lime water), air (air lime) or organic (bitumen), which significantly improve the mechanical strength of the composite material crafted, the water resistance relative to the blocks of traditional adobe and also the dimensional stability is also improved (Morel, 2001; Toupe, 2015; Taâllah, 2014). These solutions already mentioned allowed the ground material to achieve physical and mechanical performance similar to the clay and masonry with concrete blocks, rather than the molded wet method by hand generally used for adobe.

In order to address the excessive dimensional change problem of molded earth another solution was checked in which is the granular matrix correction by adding to the matrix of mineral inclusions. The fibers used as reinforcement, distributed throughout the mass of the material tensions caused by the removal of the clay Taâllah (2014), reduce the size of cracks caused by shrinkage and improves the durability and tensile strength.

### Our approach: Adobe stabilized and reinforced with treated rush fibers

Our objective was therefore to formulate an earth mortar allowing the making of blocks of raw earth (adobe), intended for the construction of works such as walls, arches and domes. These earth blocks must have a compressive strength similar to that of fired bricks and dimensional stability characterized by limited shrinkage in order to avoid the appearance of microcracks. For this, three approaches have been adopted:

- Granular correction,
- Stabilization with hydraulic and aerial binders (cement, lime and plaster),
- Reinforcement with vegetable fibers from rush treated chemically.

Thanks to the chemical process by alkalization (8% NaOH with $Na_2S_2O_4$ and NaOCl) we were able to develop rush plant fibers of very high characteristics with a diameter reduced to 40ìm, a high density of 1.25 g/cm$^3$, a breaking stress in tension of 1800 MPa and a modulus of elasticity of 122 GPa.

### Origin of used Adobe

Our choice fell on the earth of the site of Sidi Amor (Borj Touil) in the governorate of Ariana, Tunisia, with which was carried out a pilot construction in classic adobe (mortar of raw earth mixed with straw and the water). Figures 9 and figure 10 show the location of the earth extraction site that is the subject of our research.

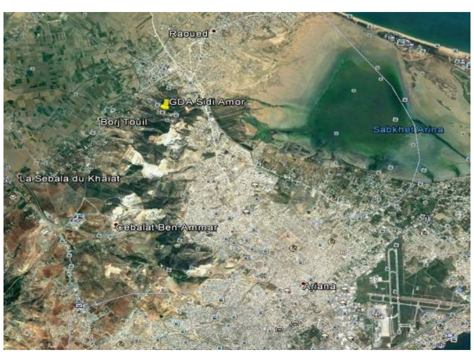


**Fig. 9.** Aerial photos of the earth extraction zone used in this study (Pilot site - GDA - Sidi Amor - Ariana)

### Grain size of the earth used

Raw earth is said to be exploitable if it has a continuous particle size and as linear as possible. The sizes

**Fig. 10.** Adobe matrix extraction site (Pilot site - GDA - Sidi Amor - Ariana)

of the grains constituting the earth chosen for this study were determined by two methods, namely:

- The particle size analysis by dry sieving for the granular fraction with a diameter greater than 80 µm in accordance with standard NT 21.07 (1984). This test is carried out at the mechanical laboratory of the national school of architecture and town planning (ENAU) - Tunisia.
- Granulometric analysis by laser diffraction granulometer (Brand: Mastersizer 2000 from Malvern) by dry method for the granular fraction with a diameter of less than 80 µm. This test is carried out at the National Institute for Research and Physical-Chemical Analysis (INRAP) - Tunisia.

We carried out a particle size analysis on the soil sample in order to be able to locate its granularity compared to a conventional particle size spindle. This test was repeated three times on three samples extracted from three different places from the stock brought from the site, in order to be able to ensure the exact granular distribution to be taken into account in our case study. The particle size analysis shows that it is a very fine soil (50% <0.05 mm) (Fig-

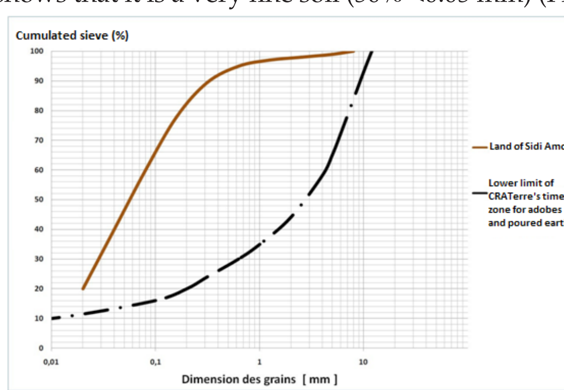


**Fig. 11.** Granulometry of the earth used compared to the reference curve

ure 11) and its comparison with the limit zone characteristic of the earth developed by CRATerre for the preparation of adobe or of molded earth mortar, indicates the possibility of its use for the elaboration of adobe.

Having a particle size curve in the particle size zone in general or above and close to this lower limit of the particle size zone relating to adobes in particular means that it is an optimal particle size and this guarantees a certain security. in works constructed from this material. But that does not mean that if it is not, in whole or in part, located in the spindle it is not possible to build with this earth. But there will be major problems (withdrawal, etc.) that will have to be solved and it is possible, by mixing with another soil rich in elements missing from the first, to obtain a satisfactory product.

**Plasticity of the earth used - The limits of Atterberg**

To assess the effect of the earth's contact with water and to be able to quantify its passage from the solid state to the plastic state then to the liquid state and thus determine its plasticity index, we carried out limit tests of Atterberg on three samples of the earth used and which showed that the plastic limit is 16%, that the liquid limit is 22.5% and that the plasticity index is 6.5%. We deduce from the positioning of these values on the plasticity chart (Figure 12) according to the LCPC-USCS classification (ASTM D2487-11) (Kanema, 2016), that this earth is classified as a little plastic silt which needs a large amount of water to be able to pour it into molds or formwork.

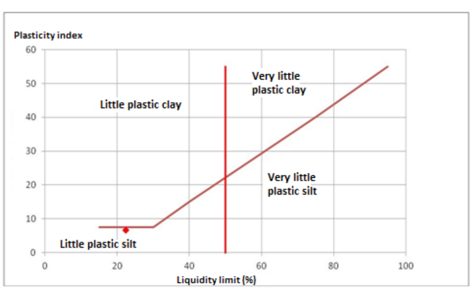


**Fig. 12.** Plasticity of used Adobe

## Densities of used Adobe

**Apparent density**

The apparent density (ρa) was determined from the ratio of the weight of the sample by its apparent volume according to the standard in accordance with standard NT 21.05 (2002).

**Specific or actual density**

The actual or absolute density (γ) is determined according to ASTM D854 (Standard test methods for the density of soil solids using a water pycnometer) (AST, 2006; MKazmi, 2016). The values found, presented in Table 4, show a large difference which reflects the strong presence of voids between the grains of the dry soil sample.

**Table 4**. Densities used Adobe

| Properties | Value |
|---|---|
| Apparent density (ρa) | 1 g/ cm³ |
| Actual density (γ) | 2.4 g/cm³ |

These two properties which we have just mentioned, will subsequently allow us to deduce the porosity by the formula:

$$P\ (\%) = \left(1 - \frac{\rho_a}{\gamma}\right) x100 \quad (1)$$

**The chemical composition of used Adobe**

A chemical analysis was carried out on the earth used for the preparation of the mortar in order to know the chemical elements present in the earth and also to know if there are elements that are contaminants or pollutants for humans.

**Elementary chemical composition**

The values found indicated in Table 5 show that the soil of the Sidi Amor site used is highly siliceous (large presence of sand), moderately calcic (medium presence of limestone) and weakly aluminous (weak presence of clay) and very weakly ferruginous (very low presence of iron), but also it contains 17.55% of organic matter which was measured by the loss on fire test.

**Table 5.** Elementary chemical analysis of the earth used

| Elements | (%) |
|---|---|
| $SiO_2$ | 52.15 |
| $Al_2O_3$ | 6.71 |
| $Fe_2O_3$ | 3.36 |
| CaO | 16.92 |
| MgO | 0.92 |
| $Na_2O$ | 0.16 |
| $K_2O$ | 0.92 |
| $SO_3$ | < 0.01 |

In addition, a check was made on the minor elements, presented in Table n ° 6, which show us that they are in majority in the trace state (a few ppm) with however a certain presence of the element P (Phosphorus) and the element Ti (Titanium). The land of Sidi Amor can therefore be considered to be land that does not contain concentrations of elements that are contaminating or polluting for humans.

### Chemical bonds - Analysis by Fourier transform infrared spectrometry (FTIR)

Fourier transform infrared spectrometry (FTIR) is an effective technique that will allow us to analyze the chemical and structural properties of raw earth. The IR spectra were recorded at ambient temperature using a device of the Nicolet IR 200 FT-IR brand with an ATR spectrometer, equipped with a diamond crystal and in a spectral range which extends in the interval [4000-400 $cm^{-1}$].

The analysis by Fourier transform infrared spectrometry allows, by detecting the vibrations characteristic of chemical bonds, to perform the analysis of the chemical functions present in the material. It allowed us to note that the chemical bonds present in the earth used (Figure 13) are predominantly siliceous (SiO) with the presence of calcite (CaO) and a small percentage of hydroxyls (OH) attributed to Kaolinite and Illite clays.

### The mineralogy of the used Adobe

In order to mineralogically identifying the soil used, we also performed an X-ray diffraction analysis to detect and quantify the minerals existing in the sample tested. The raw earth was analyzed under ambient conditions on an X-ray diffractometer (D8 Advance, Brucker, AXS, Germany), with a voltage of 40kV and 30 mA, Cu Ka radiation (1.5418), at a scanning speed. 2°/min, and on a 2ε angle interval between 2° to 40°.

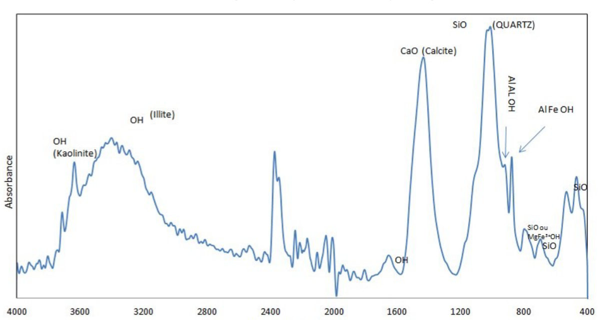


**Fig. 13.** Fourier transform infrared spectrometry of the used Adobe

The results of this XRD analysis (Figure 14) corroborate with those of the chemical analysis and infrared spectrometry, confirming that this earth is mainly siliceous (presence of Quartz), moderately dolomitic limestone and weakly clayey (Illite and Kaolinite). These proportions are acceptable in the case of adobes or molded earth.

### Characterization and treatment of rush fibers

### Vegetable rush fibers

Among the different plant species existing in Tunisia, our choice was fixed on the rush plant because of its presence throughout the Tunisian territory. The rush plant belongs to the Joncaceae family (Doat, 1991; Ribeiro, 2013), of which there are around 200 species that grow in wetlands such as the surroundings of lagoons, lakes and rivers. It is currently used to make mats, rugs, baskets, fans and baskets. In addition, it could constitute a potential source of organic matrix reinforcement (polyester resins or epoxy components) or mineral (cement or lime mortar or gypsum or natural earth). The rush used in our study (Figure 15) comes from the Amroun region in the governorate of Nabeul in north-eastern Tunisia, and the rush rod has an aver-

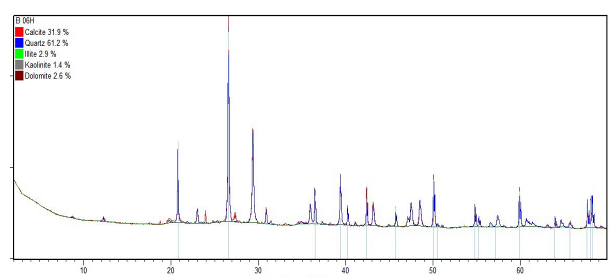


**Fig. 14.** Earth X-ray diffraction

**Table 6.** Elementary chemical analysis of the earth used

| Element | Ba | Cd | Co | Cr | Cu | Mn | Mo |
|---|---|---|---|---|---|---|---|
| ppm | 18.4 | 0.2 | 4.9 | 2.3 | 8.9 | 16.0 | 2,0 |
| Element | Ni | P | Pb | Sr | Ti | Zn | - |
| ppm | 1.1 | 148 | 2.5 | 13.1 | 92.0 | 16.0 | - |

**Fig. 15.** The rush plant (Nabeul - Tunisia)

age length of around 125 cm.

### Morphological characterization ("SEM" scanning electron microscope)

The rush plant is composed of a multitude of radiant contiguous stems as shown in Figure 15. Each of its stems is made of cellulose fibers located on the periphery and others trapped inside the stem and separated by empty alveolate cells as seen on the pictures (Figures 17 and 18) of SEM observations that we have made. The rod with its diameter of about 3300 µm cannot be used as it is as reinforcement in composites. Cellular lignin and hemicellulose cells should be removed to extract clumps of cellulosic fibers peripheral and internal fibers called ultimate fibers which have a diameter of around 300 µm as seen in Figure 18.

**Fig. 16.** The scanning electron microscope with the sputtering device used

To evaluate and see the natural rush rod and also the influence of the different treatments on the defibration of the rush fibers, their surface condition and their diameter, we used a scanning electron microscope (SEM) of the JEOL JSM 5400 type (Figure 16). The observations were made on the natural rod, fiber bundles and on isolated fibers, coated with a thin layer of gold in a JEOL JFC 1100 sputtering device (Figure 16) and scanning electron micrographs of the fibers have been saved.

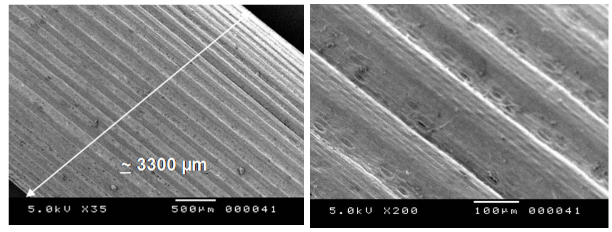


**Fig. 17.** Rod of rush observed with SEM respectively with a magnification 35 and 200 times

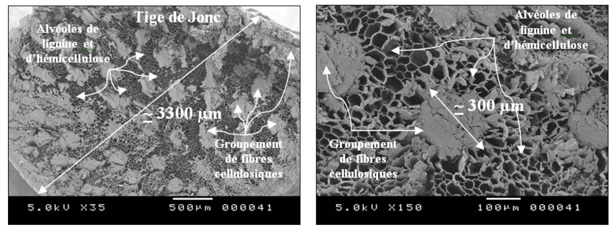


**Fig. 18.** Cross section of a rush rod observed with SEM respectively with a magnification 35 and 150 times

## Conclusion

In this research work we are interested in the earth construction method which has become one of the ecological and green alternatives allowing to save energy and preserve the environment. We started from the principle that all land could be valid for construction, even if its initial properties were not entirely suitable for the mode of construction (adobe, adobe, compressed blocks, etc.), with the application of correction particle size and / or stabilization by aerial or hydraulic binders or by reinforcement with vegetable rush fibers.

Among the different earth construction methods we have chosen to study the case of the adobe. However like other earth construction techniques, the Adobe raises certain problems of use due to its brittleness and its dimensional variation characterized by a significant shrinkage during drying.

To solve the problems of dimensional stability (drying shrinkage) and brittleness of the earth mortar, we have adopted in our study approaches of stabilization with mineral binders and reinforcement with vegetable rush fibers chemically extracted by alkalization.

In order to reduce the shrinkage phenomenon, we applied an approach of granular modification of the matrix by adding mineral inclusions. It was based on the one hand on the characterization of the material "Earth" from the granulometric, physico-chemical and mineralogical point of view, and on the other hand on the characterization of the earth mortar: the Adobe.

The addition of rush plant fibers had the effect of decreasing the thermal conductivity of the adobe on the one hand, thereby improving its thermal insulation capacity, and on the other hand improving its acoustic absorption, thereby adobe a building material having an improved capacity of thermal insulation and acoustic correction, without making it lose its property of acoustic weakening in spite of its lightening.

However, as perspectives and continuation of this work we can propose two lines of research: Study the fire behavior of materials already made other than the characterizations carried out and study the use of rush fibers in the reinforcement of the earth in other areas. other earth construction techniques (daub, mud, etc.).

## References


ASTM Committee D-18 on Soil and Rock. 2006. *Standard test methods for specific gravity of soil solids by water pycnometer*. ASTM international.

Binici, H., Aksogan, O. and Shah, T. 2005. Investigation of fibre reinforced mud brick as a building material. *Construction and Building Materials*. 19(4): 313-318.

Binici, H., Aksogan, O., Bodur, M. N., Akca, E. and Kapur, S. 2007. Thermal isolation and mechanical properties of fibre reinforced mud bricks as wall materials. *Construction and Building Materials*. 21(4): 901-906.

Daher, R. 2015. *L'architecture en terre crue dans la vallée du Jourdain; une filière en reconstruction… temporaire* (Doctoral dissertation, Université Paris-Saclay).

Dallel, M. 2012. *Evaluation du potentiel textile des fibres d'Alfa (Stipa Tenacissima L.): Caractérisation physico-chimique de la fibre au fil, Ph.D Thesis*.

Doat, P., Hays, A., Houben, H., Matuk, S. and Vitoux, F. 1991. Building with earth. *The Mud Village Society. New Delhi*.

Fehri, F. 2015. *Valorisation des plantes de la région de Kasserine (Tunisie) dans le domaine papetier*, PhD thesis, University of Sfax, Tunisia.

Fratini, F., Pecchioni, E., Rovero, L. and Tonietti, U. 2011. The earth in the architecture of the historical centre of Lamezia Terme (Italy): Characterization for restoration. *Applied Clay Science*. 53(3) : 509-516.

Houben, H. and Guillaud, H. 2006. CRATerre: Traité de Construction en Terre. *Éditions Parenthèses: Marseille, France*.

Kanema, J. M., Eid, J. and Taibi, S. 2016. Shrinkage of earth concrete amended with recycled aggregates and superplasticizer: Impact on mechanical properties and cracks. *Materials & Design*. 109: 378-389.

Kariyawasam, K. K. G. K. D. and Jayasinghe, C. 2016. Cement stabilized rammed earth as a green construction material. *Construction and Building Materials*. 105 : 519-527.

Kazmi, S. M., Abbas, S., Saleem, M. A., Munir, M. J. and Khitab, A. 2016. Manufacturing of green clay bricks: Utilization of waste sugarcane bagasse and rice husk ashes. *Construction and Building Materials*. 120 : 29-41.

Kianfar, E. and Toufigh, V. 2016. Reliability analysis of rammed earth structures. *Construction and Building Materials*. 127: 884-895.

Kozlowski, R. and Wladyka-Przybylak, M. 2004. Uses of natural fiber reinforced plastics. In: *Natural Fibers, Plastics and Composites* (pp. 249-274). Springer, Boston, MA.

Luo, C. J., Stoyanov, S. D., Stride, E., Pelan, E. and Edirisinghe, M. 2012. Electrospinning versus fibre production methods: from specifics to technological convergence. *Chemical Society Reviews*. 41(13): 4708-4735.

Meukam, P. 2004. Valorisation des briques de terre stabilisées en vue de l'isolation thermique de bâtiments. *Université de Yaoundé I*.

Morel, J. C., Mesbah, A., Oggero, M. and Walker, P. 2001. Building houses with local materials: means to drastically reduce the environmental impact of construction. *Building and Environment*. 36(10): 1119-1126.

Müssig, J. and Martens, R. 2003. Quality aspects in hemp fibre production—influence of cultivation, harvesting and retting. *Journal of Industrial Hemp*. 8(1) : 11-32.

Nair, Gopu and Rho, Denis and Raghavan, Vijaya. 2013. Application of Electro-Technologies in Processing of Flax Fiber. *Fibers (MDPI)*. 1. 21-35. 10.3390/fib1020021.

Nakano, Y., Yamaguchi, M., Endo, H., Rejab, N. A. and Ohtani, M. 2015. NAC-MYB-based transcriptional regulation of secondary cell wall biosynthesis in land plants. *Frontiers in Plant Science*. 6 : 288.

Pacheco-Torgal, F. and Jalali, S. 2012. Earth construction: Lessons from the past for future eco-efficient construction. *Construction and Building Materials*. 29 : 512-519.

Piattoni, Q., Quagliarini, E. and Lenci, S. 2011. Experimental analysis and modelling of the mechanical behaviour of earthen bricks. *Construction and Building Materials*. 25(4): 2067-2075.

Ragoubi, M. 2010. *Contribution à l'amélioration de la compatiblilité interfaciale fibres naturelles/matrice thermoplastique via un traitement sous décharge* *couronne* (Doctoral dissertation, Nancy 1).

Ribeiro, H., Almeida, C. M. R., Mucha, A. P., Teixeira, C., and Bordalo, A. A. 2013. Influence of natural rhizosediments characteristics on hydrocarbons degradation potential of microorganisms associated to Juncus maritimus roots. *International Biodeterioration & Biodegradation*. 84: 86-96.

Saad, H. 2013. *Développement de bio-composites à base de fibres végétales et de colles écologiques*, PhD thesis, the University of Pau, France.

Silveira, D., Varum, H., Costa, A., Martins, T., Pereira, H. and Almeida, J. 2012. Mechanical properties of adobe bricks in ancient constructions. *Construction and Building Materials*, *28*(1), 36-44.

Taâllah, B. 2014. *Study of the behavior of the physical-mechanical block of land with compressed fibers*, PhD Thesis, University Mohamed Khider, Algeria.

Toupe, J. L. 2015. *Optimisation des propriétés mécaniques de composites à base de fibres naturelles: application à un composite de fibre de lin avec un mélange de polyéthylène/polypropylène d'origine post-consommation,* Ph.D. Thesis, Laval University.

Trimeche, M., Smaoui, H., Cheikh, R. B., Smida, M., Rebaï, T., Keskes, H. and Oudadess, H. 2016. Elaboration and evaluation of a composite bone substitute based on â-tcp/dcpd and phbv, preliminary results. *Biomedical Engineering: Applications, Basis and Communications*. 28(05) : 1650031.

Villamizar, M. C. N., Araque, V. S., Reyes, C. A. R. and Silva, R. S. 2012. Effect of the addition of coal-ash and cassava peels on the engineering properties of compressed earth blocks. *Construction and Building Materials*. 36: 276-286.