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Characterization of Earthen Construction in South-Eastern Morocco

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Abstract: The characteristic architecture in the oases of south-eastern Morocco is that of raw earth construction. This is done through two techniques: rammed earth and adobe. This work is carried out with the aim of preserving this ancestral know-how by studying a construction dating back two centuries. The first step is to characterize a soil extracted from the remains of an old building, the grain size and plasticity of the soil showed that it was not very clayey and moderately plastic and that it was suitable for earth construction. Secondly, the study focuses on the mechanical resistance of blocks extracted from the remains studied, the result obtained satisfies all the standards. In order to characterize the durability of the adobe, we made samples of the earthen bricks with a similar soil and the study showed good durability of the adobe construction, the raw earth is a material that can stand in time. And finally, the reusability of the earth material from old buildings has been studied, the results have shown that raw earth is a perfectly reusable material, which makes it the ideal ecological material.

Key words: Vernacular construction, adobe, soil characteristics, mechanical characteristics.

1. Introduction

For thousands of years, construction has been done exclusively with local materials. If we take the example of the Great Wall of China, we can see that it adapts throughout its course to the nature of the ground on which it is built. Thus, we find parts built of stone on the rock, earth on the earth and sometimes even sand in some desert parts. Given the size of the territory crossed by this building, it was built using local materials in order to limit the transport of the extraction area to that of the construction site. Exploiting local materials to build your home is a universal behavior. And often, land is the only material available. Studies estimate that "at least 30% of the world's population lives in earthen buildings and 17% of buildings inscribed on UNESCO's World Heritage List are earthen architectural works" [1]. Fig. 1 shows that raw earth construction is widely distributed around the world.

For more than a thousand years, raw earth has been a material of choice for construction in the oases of south-eastern Morocco. These oases are known by the presence of various large fortresses known as ksar (or ksour in plural). These constructions represent an architectural part of the national heritage and also of the UNESCO world heritage such as the ksar ait Benhaddou (Fig. 2). El Khorbat ksar, located near Tinejdad city, is an example of vernacular architecture tackled in many studies [2] (Fig. 3). These constructions were made using two main techniques: rammed earth and adobe. The rammed earth technique consists of tamping damp earth in a formwork. The earth is poured into a formwork in layers. Adobe is a raw earth brick shaped by hand or in a wooden mold in a plastic state and air-dried. This is often reinforced with straw fibers.

Earth construction provides thermal compliance in an arid climate, which is very hot in summer and cold in winter. It reduces heating and cooling energy requirements through heat storage capacity of the rammed earth materials, which is beneficial to the environment. In addition, raw earth is a material with low gray energy and its operation meets environmental

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Fig. 1 Distribution of raw earth construction around the world [1].

Fig. 2 Ksar Ait Benhaddou.

Fig. 3 The raw earth construction in Tinejdad oasis.

requirements. However, the use of this material faces many obstacles as the non-uniformity unlike cement concrete: the material changes enormously from one region to another and from one deposit to another.

This work focuses on raw earth used in the city of Tinjedad, located in a south-eastern oasis of Morocco, to characterize the material used in 200 years old building in the ksar of gardmit and compare it to the standards, then the mechanical resistance of several blocks extracted from old constructions were measured and compared to standards, which made it possible to draw conclusions regarding the durability of the earth material. The reusability of the earth was also studied by reusing the earth from old constructions to make new adobes.

The soil used for this study is extracted in the city of Tinejdad, in the central-eastern part of the Kingdom of Morocco, a region known for its traditional earthen citadel architecture.

2. Experimental Methodology

2.1 Raw Earth Characterization

Initially, the study was interested in the characterization of the nature of the soil used in the making of three blocks extracted from several walls of the old citadel (ksar) of gardmit in the municipality of Tinejdad in the south-eastern Morocco.

2.1.1 Granulometry

The particle size analysis is carried out in two phases:

(1) The first: the particle size analysis by sieving

It concerns the soil fractions with a diameter greater than 80 µm and was carried out in accordance with standard NF P 94-056, the samples studied are sieved under a stream of water, after immersion in water for 24 h. The refusals are oven dried to constant mass. Then, the residue of each sieve is weighed.

(2) The second phase: particle size analysis by sedimentation

It concerns the fraction of the soil less than 80 µm and is carried out in accordance with standard NF P 94-057. The principle of sedimentation uses the difference in the fall of the particles, in a test tube of 2 L of distilled water. It consists of letting the particles in suspension settle at the bottom of the test tube, according to their diameters. Using a hydrometer, the density is measured regularly over time and at a given height. These measurements make it possible to calculate the proportions of the particles of each diameter, which are recorded in a table and used in grain size curves.

2.1.2 Plasticity

This test is carried out on the fraction less than 400 µm and consists in varying the water content of the material in order to assess its consistency. The test is carried out in two phases and in accordance with Standard NF P 94-051: A first phase in which the water content is sought for which a groove made in a soil placed in a cup of imposed characteristics closes when the latter and its content are subjected to repeated shocks. In a second phase, we look for the water content for which a roll of soil, of fixed size is made manually, cracks. The Atterberg limits correspond to the thresholds of passage from the solid state to the plastic state: the PL (plastic limit); and from the plastic state to the liquid state: the liquidity

Fig. 4 200-year-old walls.

limit LL The interval between these two limits defines the extent of the domain of plasticity: plasticity index PI.

2.1.3 The Methylene Blue Test (BV)

The aim of this test is to characterize the specific surface of the clay fraction of a material. The result of the test depends directly on the nature and the amount of this fraction in the material, it tells us about the sensitivity of the clay to water and therefore about its swelling shrinkage properties.

The test is carried out on the fraction of particles with a diameter of less than 5 mm. It consists of measuring, by assay, the amount of methylene blue that can be adsorbed by a material suspended in water and with permanent stirring. The method consists of an injection, in the aqueous bath containing the test sample, of elementary doses of 5 cm^3 of a solution of methylene blue. The adsorption of the blue is checked 1 min after each addition, by performing a task with a glass rod on a filter paper. The resulting stain consists of a dark blue nucleus and a transparent halo, indicating that the injected blue is fully adsorbed and the test is negative. When the halo begins to turn blue, adsorption is allowed to take place. If after 5 min the halo persists, the degree of adsorption saturation is reached and the test is positive. The total quantity of methylene blue solution used is recorded.

2.1.4 Optimal Water Content

In the rammed earth technique, the material is used in formwork by dynamic compaction by means of manual or mechanical tamping. This technique of construction on site is similar to "Proctor" tests in laboratory. These tests will make it possible to determine the moisture content of the material during compaction to obtain maximum dry density. They will also allow monitoring its implementation.

The density of the material is measured for different water contents, in accordance with the standard (NF P94-093); the results determine the optimum water content.

2.2 Mechanical Test Plan and Samples

This study is interested from a mechanical point of view to the compressive strength, three samples (W1, W2 and W3) were extracted from three blocks of old walls, these samples went through a concrete saw to make bricks of 10 × 10 × 10 cm^3, the test is performed using a press with a capacity of 3,000 kN in accordance with the standard NF P 18-406, the loading speed is 300 N/min.

Then, in order to study the durability of the raw earth construction, bricks (B1, B2 and B3) were shaped from earth extracted from the same area and having characteristics very similar to the earth constituting the studied walls.

2.3 Reusability

The construction in raw earth is certainly an ecological solution, here the study consists in going even further in this aspect of the earth material, by reusing the earth extracted from an old construction (Fig. 4).

Then, in order to study the reusability of the raw earth construction, bricks (R1, R2 and R3) were shaped from the old wall's earth.

Then the results are compared with those obtained with raw earth extracted from deposits on site.

3. Results and Discussion

3.1 Raw Earth Characteristics

Tables 1 and 2 show the characteristics of the raw earth used in three old walls “W1”, “W2”, “W3” and the raw earth extracted from deposit on site “N”.

The results of the particle size analysis indicate that the soil in the old walls contains between 12% and 16% gravel, approximately 60% sand, 15% silt and between 12% and 16% clay. The Atterberg limits are respectively between 21.3% and 23.5%, for the liquidity limit; between 12.9% and 14.8% for the PL and between 8.4% and 9.3% for the plasticity index.

With regard to the earth mined on-site from the on-site deposit, the particle size analysis indicates that the soil contains approximately 13% gravel, 63% sand, 12% silt and 12% clay. The Atterberg limits are respectively 20% for the liquidity limit, 12.7% for the plasticity limit and 7.5% for the plasticity index. Based on the LCPC “Central laboratory of Ponts et Chaussées” [3] and USCS “Unified Soil Classification System) [4], the different soils used are classified as clayey sand. These floors meet the requirements of Moroccan regulations for earthquake-resistant earth constructions for adobe, with the exception of the liquidity limit which is below the minimum threshold of 25% [6].

Table 1 Raw earth granulometry.

	Gravel (20-2 mm)	Coarse sands (2-0.2 mm)	Fine sands (0.2-0.06 mm)	Silt (0.06-0.02 mm)	Fine Silt (0.02-0.002 mm)	Clay (< 0.002 mm)
% “W1”	12	25	35	7	8	13
% “W2”	10	28	31	6	9	16
% “W3”	13	31	30	6	8	12
% “N”	13	30	33	5	7	12

Table 2 Raw earth characteristics.

	Fine content (%)	Liquidity limit (%)	Plasticity limit (%)	Plasticity index (%)	Methylene blue value
“W1”	28	22.5	13.2	9.3	2.88
“W2”	31	23.5	14.8	8.7	2.92
“W3”	26	21.3	12.9	8.4	2.8
“N”	24	20.2	12.7	7.5	2.75

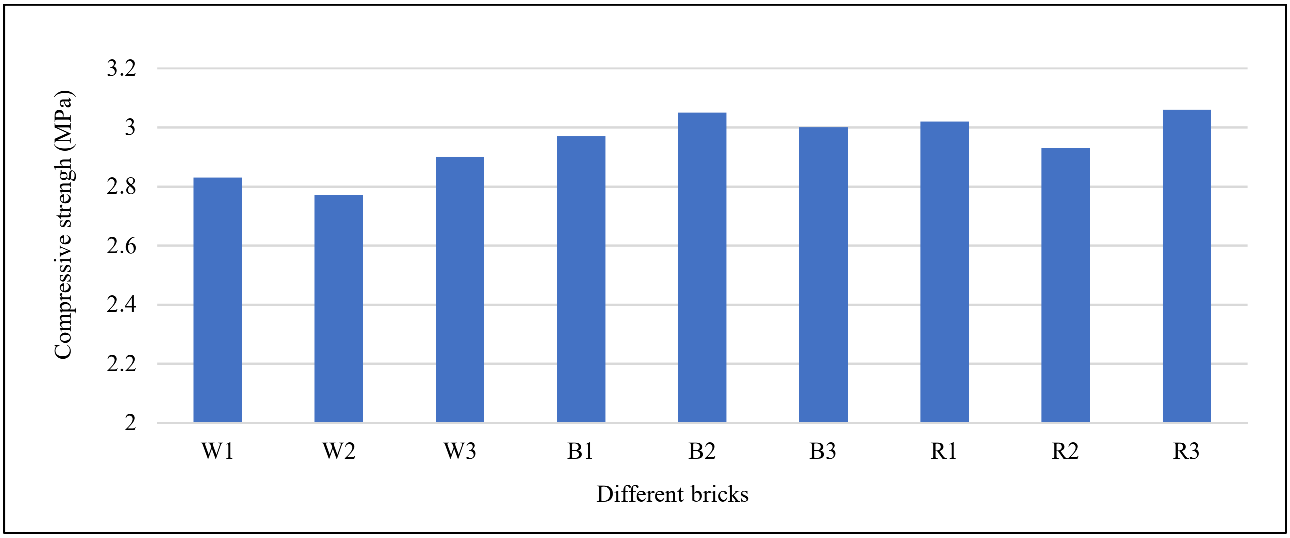

Fig. 5 Compressive strength of different bricks.

3.2 Mechanical Characteristics

The mechanical characterization of the adobe samples was carried out to characterize and compare the mechanical resistance to compression of different bricks, those of the old walls W1, W2 and W3, those built from the earth extracted from the deposit in the same zone B1, B2 and B3. The various samples meet the required compressive strength, the most demanding standard, being the New Mexico code, imposes a minimum compressive strength of 2 MPa [12].

Fig. 5 shows the compression resistances of the different bricks: the bricks extracted from the old walls: W1, W2 and W3; bricks made with raw earth extracted from the on-site deposit B1, B2 and B3; and bricks made by reusing soil from old walls R1, R2, R3.

4. Conclusion

The purpose of this research was first to study the raw earth used for traditional construction in the Moroccan south-east, used 200 years ago, it meets the requirements of the Moroccan standard, and the resistance to the compression of different blocks extracted from old walls meets different standards. The study then concerned the durability of the material by comparing the compressive strengths of old “W” bricks with new “N” bricks, the results obtained showed that the earthen material retains good compressive strength after two centuries. The research finally treated the reusability of raw earth used in these same walls, it was reused for making bricks, these bricks were then compared with bricks constructed from a very similar earth deposit, this comparison showed that the earth material is perfectly reusable.

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