THE MATERIALS UTILISED IN THE EARTHEN BUILDINGS SITED IN THE DRÂA VALLEY (MOROCCO): MINERALOGICAL AND MECHANICAL CHARACTERISTICS

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Abstract
The paper reports the results of an experimental investigation carried out in order to determinate the physical and mechanical properties of the earth material utilized in the Drâa valley (Morocco) for the building made of pisé and adobe. In Drâa valley, a millennial heritage of earthen buildings of great architectonic value (ksar and kasbah) is present. The analyzes were carried out on different kind of earth, utilized both for adobe and pisé building. The earths were characterized through the study of the mineralogical composition, the determination of the grain size and the consistency limits. The mechanical properties were determined both in laboratory through mechanical test and in situ through sclerometers analysis. The results of the compositional, physical and mechanical analyses makes it possible to evaluate the suitability of the utilized earths as construction materials and to propose improvement methods.

1. THE EARTHEN BUILDING HERITAGE OF THE DRÂA VALLEY (SOUTHERN MOROCCO)

The Atlas chain not only divides geographically Morocco in two sides but also strongly affects traditions, architecture and cultural heritage. In the Drâa region which is a wide valley that cut the Anti Atlas up to the narrow passage of Beni Slimane, more than 300 *ksur* can be found amid palm forests. The *ksur* are fortified villages square or rectangular in shape surrounded by towered made of stone and earth while the buildings on the inside are made only of earth according to the adobe and pisé technology. The Drâa valley is known as the valley of the *kasbah*, fortified houses belonging to wealthy families and administrators of the territory and villages, constructed entirely with earth.

The external walls and the partition walls are realised with the pisé building technique which makes it possible to realise very high walls depending on the width of the wall itself. On the contrary the adobe building technique is utilised for the pillars and decorative elements both inside the patios and at the top of the buildings.

All along the Saharan side of Morocco, earth is the most important building material with an immense diffusion both in the ordinary buildings and in the monumental constructions strongly characterising the building identity of the site and as a consequence the landscape with amazing aesthetic results. The earthen buildings together with a suitable choice of the living typology, assure a good adaptation to the climatic conditions of the site thanks to the low thermal conductivity which isolate from the external heat maintaining a thermal comfort inside the house. Moreover earth is a material easy to find, available in very large quantities with consequent low costs of supply and transport.

The restoration of the existing building heritage is not sufficient to preserve and enhance such a valuable building typology but this goal can be achieved only together with the promotion of the present use of this building technology according to the tradition but nevertheless adapted to the present needs. Therefore the knowledge of the local building technology together with the characteristics of used “earth” is necessary in order to achieve these aims.

Unfortunately as already happened in Europe in the past century, also in Morocco the traditional “building know how" risks to disappear because of the diffusion of the reinforced concrete, considered a symbol of progress even if often the results are completely inadequate with respect to the environmental conditions.

This paper discuss the results of the compositional, physical and mechanical tests carried out on earth samples used as building material in the Drâa region with the aim to know the local building techniques and possibly to improve them.

2. MATERIALS AND METHODS

Earth samples taken from different villages of the Drâa valley (Amzrou, M’Hamid, Tamgrout, Tissergat and Zagora) and used for the pisé or adobe building technique have been characterised from the mineralogical and physical point of view. At the same time, sclerometric tests have been carried out on some pisè and adobe buildings in Tissergat and Zagora together with laboratory mechanical tests on M’Hamid, Tissergat and Zagora adobe in order to measure the compressive strength. The correlation between the data collected in laboratory and on-site makes it possible to evaluate the suitability of the earth as building material and to envisage and develop an improvement of the procedures.

The compressive strength performed both on unweathered materials and on samples exposed to aging cycles, is the most important mechanical parameter to be considered in a masonry. Nevertheless the durability and the mechanical strengths depend on the compositional characteristics (mineralogy, granulometry) which on their turn influence the consistency limits. Therefore the compositional and physical characterisation makes it possible to give a reason of the behaviour of the earth material and to envisage possible corrections like adding a temper or fibres, mixing for more plasticity, changing the degree of compaction and the amount of water, and other additives.

2.1 Sampling

The following samples have been considered:
Sample A: earth for pisé (Amzrou);
Sample B: adobe of new production (Tamgrout);
Sample C: in situ adobe (old) (Tamgrout);
Sample D: earth from the palm forest used to produce adobe or mixed with earth E in order to produce pisé (Tissergat);
Sample E: earth from the mountain used to produce pisé, alone or mixed with earth D (Tissergat);
Sample F: adobe of new production (Zagora);
Sample G: adobe of new production (M’Hamid);
Sample H: in situ adobe, monumental door (Tissergat);
Sample L1: pisè masonry, defence tower (Tissergat);
Sample L2: pisè masonry, monumental door (Tissergat);
Sample L3: pisè masonry, defence walls (Tissergat);
Sample L4: pisè masonry, house wall (Tissergat);
Sample L5: pisè masonry, house wall (Tissergat);
Sample L6: pisè masonry, house wall (Tissergat);

Sample L7: pisè masonry, house wall (Tissergat);
Sample L8: pisè masonry, monumental door (Zagora);
Sample L9: pisè masonry, defence walls (Zagora);
Sample L10: pisè masonry, house wall (Zagora);
Sample L11: pisè masonry, house wall (Zagora);
Sample M1: adobe masonry, monumental door (Zagora);
Sample M2: adobe masonry, house wall (Zagora);
Sample M3: adobe masonry, house wall (Zagora);
Sample M4: adobe masonry, house wall (Zagora).

On the samples A, B, C, D, E, F, G, H the following analyses were performed:

- determination of the principal mineralogical composition and clay mineral composition through x ray diffraction (XRD);
- determination of the amount in calcite through calcimetry;

On the samples A, B, C the following analyses were performed:

- granulometric analysis through sieving (according to the ASTM D 2217 normative) and sedimentation (AASHTO T 88-72) ;
- study of the physical characteristics through determination of the liquid (Wl%) and plastic (Wp%) limits (Atterberg limits) that make it possible to compute the plasticity index (Ip%) (CNR-UNI 100014) and to classify the earth material according to the Casagrande Chart.

On the adobe samples F, G, H three point bending tests were also carried out in order to determine indirectly the compressive strength (multiplying by 8 the tensile strength).

On samples L1 to L11 and M1 to M4, in situ Proceq pendulum hammer type PM (range 0.2-5 N/mm^2) analysis was carried out in order to determine indirectly the compressive strength through the superficial hardness measurement. The results are affected by a high degree of uncertainty but still provide reference data, which are more meaningful if accompanied by some results from laboratory tests.

3. THE COMPOSITIONAL AND PHYSICAL CHARACTERISATION - RESULTS AND DISCUSSION

The results of the performed tests make it possible to draw the following considerations:

As regards to **sample A**, the mineralogical analysis (tables 1 and 2) displays the composition of a lean earth because of the low amount in clay minerals (23%) with respect to the sandy fraction (77%) composed mainly by quartz. Moreover the low amount of smectite (a swelling clay mineral) with respect to the other not swelling clay minerals (illite, kaolinite and chlorite), does not permit to the material to retain a large amount of water with consequent low plasticity and low shrinkage. This behaviour is confirmed by the plasticity parameters (Wl =18.5%, Wp =16.7%, Ip =1.80%) which values permit the following classifications (figure 1):

- activity coefficient A = 0.17 (not active earth);
- classification according to AASHO: A-4 class: *low compressibility silty earth*;
- classification according USCS: *Lp class (low plasticity silt)*.

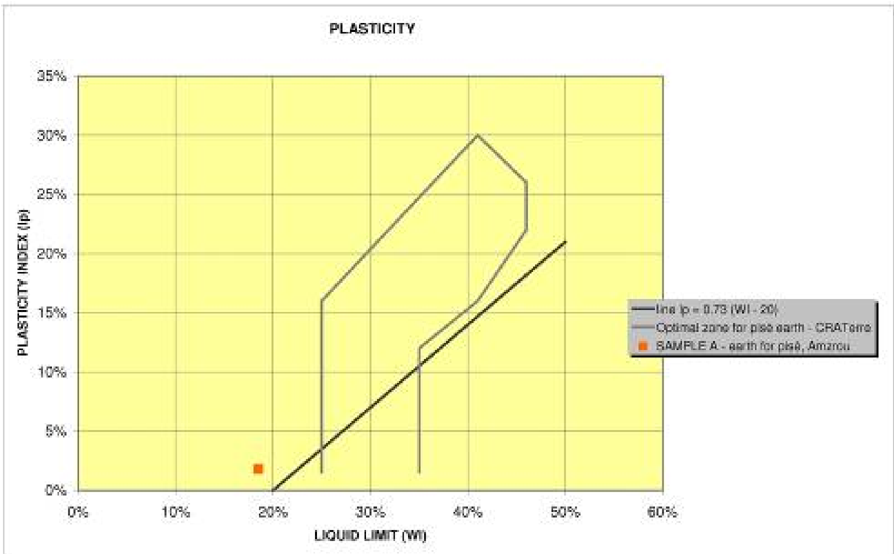
The granulometric curve of sample A (figure 1) does not fit in the field of admissibility defined by CRATerre particularly with reference to the classes of higher dimensions (sand and gravel) while it fits well for the finer dimensions classes (silt and clay) which have a percent on the total of 57.5%. With reference to this percentage the material can be defined a *fine grained earth*.

Table 1. Main mineralogical composition. (credits: Baglioni E. and Fratini F., 2009)

MAIN MINERALOGICAL COMPOSITION								
	SAMPLE A	SAMPLE B	SAMPLE C	SAMPLE D	SAMPLE E	SAMPLE F	SAMPLE G	SAMPLE H
QUARTZ	42%	37%	37%	15%	33%	25%	32%	22%
FELDSPARS	15%	9%	3%	8%	17%	11%	13%	6%
CALCITE	15%	13%	13%	7%	6%	8%	9%	7%
DOLOMITE	5%	3%	2%	3%	3%	3%	3%	3%
CLAY MINERALS	23%	38%	45%	67%	41%	53%	43%	62%

Table 2. Mineral clay composition. (credits: Baglioni E. and Fratini F., 2009)

CLAY MINERAL COMPOSITION								
	SAMPLE A	SAMPLE B	SAMPLE C	SAMPLE D	SAMPLE E	SAMPLE F	SAMPLE G	SAMPLE H
KAOLINITE	20%	25%	25%	25%	25%	25%	20%	25%
ILLITE	40%	40%	40%	45%	40%	55%	40%	40%
CHLORITE	20%	10%	15%	15%	15%	20%	20%	20%
SMECTITE	20%	25%	20%	15%	20%	tracce	20%	15%



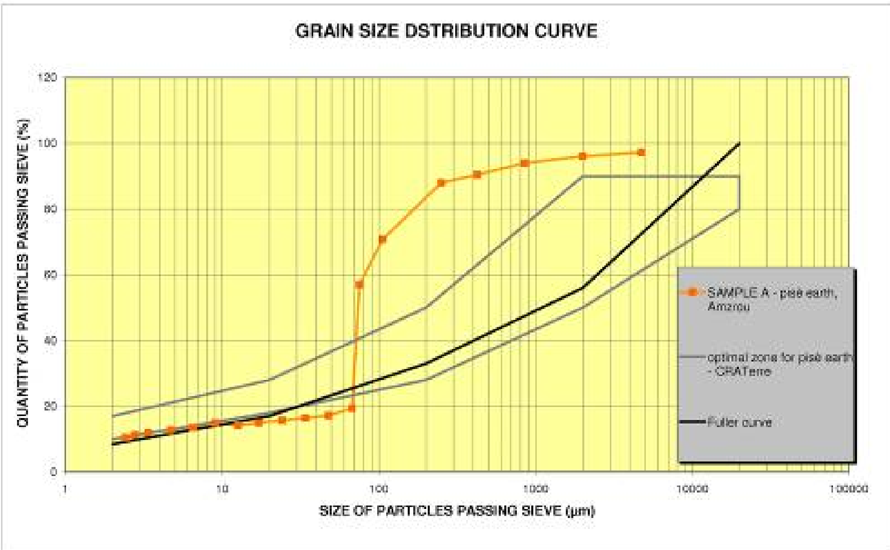


Fig. 1 – Sample A, plasticity and grain size distribution curve.
(credits: Baglioni E. and Rovero L., 2009)

As for **sample B**, the mineralogical composition (tables 1 and 2) displays a higher amount of clay minerals (38%) and a sandy framework of 62% composed mainly by quartz. With respect to sample A, the higher amount of clay minerals together with the higher amount of smectite in the clay fraction, determine a slight higher plasticity as indicated by the plasticity parameters (Wl =21%, Wp =17.2%, Ip =3.80%). These data permits the following classifications (figure 2):

- activity coefficient A = 0.12 (not active earth);
- classification according to AASHO: A-4 class: *low compressibility silty earth*;
- classification according USCS: *Lp class (low plasticity silt).*

The granulometric curve of sample B (figure 2) fits in the field of admissibility defined by CRATerre even if with an irregular shape: there is a sharp increase for the grains of 200 µm (meaning that this class is too abundant) while for the granulometric classes larger than 400 µm the curve is almost horizontal meaning that such classes are not represented.

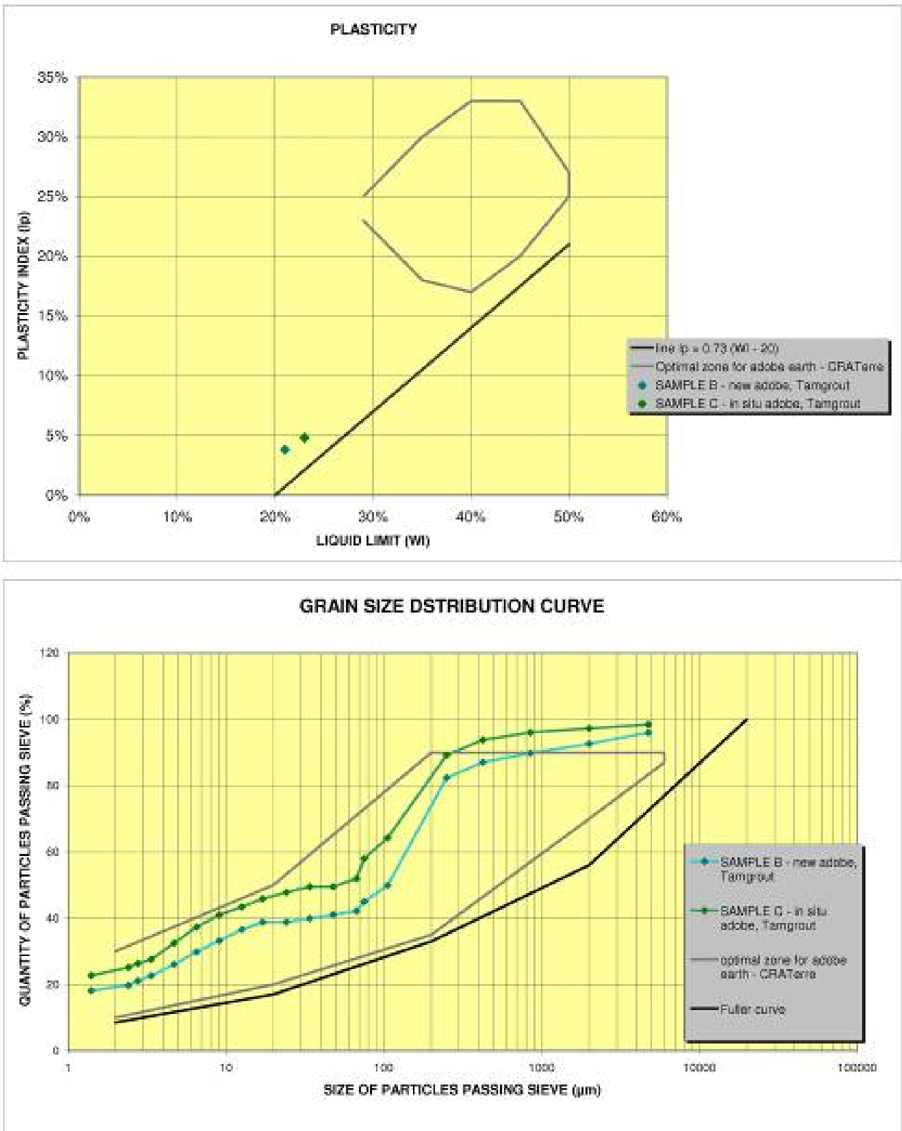


Fig. 2 – Samples B and C, plasticity and grain size distribution curve.
(credits: Baglioni E. and Rovero L., 2009)

In **sample C** the mineralogical composition (tables 1 and 2) displays a quite high content in clay minerals (45%) and a sandy framework yet composed mainly by quartz.

The high amount in clay minerals together with the presence of smectite gives rise to a quite plastic behaviour as showed by the plasticity parameters (Wl = 23%; Wp = 18.2%; Ip = 4.80%). Nevertheless these data, according to AASHO and USCS, make it possible to classify this material as a low plasticity earth (figure 2):

- activity coefficient A = 0.13 (not active earth);
- classification according to AASHO: A-4 class: *low compressibility silty earth*;
- classification according USCS: *Lp class (low plasticity silt).*

The granulometric curve of sample C (figure 2) shows the same shape as sample B.

As regards to **sample D**, the limits of consistency have not been determined but, given the high content in clay minerals (67%) (table 1), the earth material should have a quite plastic behaviour, nevertheless higher than sample C.

Also for **samples E, F G** and **H** the limits of consistency have not been determined but given the amount of clay minerals, the following considerations can be drown on the basis of the mineralogical composition:
- **sample E**: 41 % of clay minerals, amount in between that of sample B and sample C, 20 % of smectite with respect to the total of the clay minerals. The earth should display limits of consistency intermediate between the two samples;
- **sample F**: 53 % of clay minerals, amount in between sample B and D, absence of smectite. The earth should display limits of consistency similar to sample C;
- **sample G**: 43 % of clay minerals, amount similar to sample C, 20 % of smectite. The earth should display limits of consistency similar to sample C;
- **sample H**: 62% of clay minerals, amount slightly lower than sample D, 15 % of smectite. The earth should display a plasticity slightly lower than sample D.

4. MECHANICAL CHARACTERIZATION

4.1 Three point bending tests

The 3-point bending test was performed on three adobes collected in the sites of M'Hamid, Tissergat and Zagora (figure 3). From the test the maximum tensile strength of the samples is obtained and, in indirect way, an indicative value of compressive strength can be obtained multiplying the results by an amplifier coefficient, chosen equal to 8.

The results are the following:

- for Zagora adobe (sample F) a tensile strength of 0.28 MPa and a compressive strength of 2.2 MPa.
- for the M'Hamid (sample G) adobe a tensile strength of 0.18 MPa and a compressive strength of 1,46 MPa;
- for Tissergat adobe (sample H) a tensile strength of 0.35 MPa and a compressive strength of 2.8 MPa.

Fig. 3 – Sample F and G three point bending tests. (credits: Rovero L., 2009)

4.2 In situ tests of the compressive strength through sclerometer

The tests for the in situ determination of the compressive strength have been performed at Zagora and Tissergat on pisé and adobe masonries both of fortifications and houses. The compressive strength has been determined with a Schmidt-hammer, type PT (Proceq) (see figure 4), designed for the non-destructive testing of light weight concrete, gypsum and similar extremely soft building materials, measuring in the range 0.2-5 MPa compressive strength. The reliability of the results obtained with this instrument has been verified through a comparison with the compressive strength determined with monoaxial compression test.

In order to have reliable data, a statistically significant number of tests has been performed computing the mean value and the variation coefficient (v.c.):

- a total of 70 tests on pisé masonries at Tissergat (samples L1 to L7) mean compressive strength 2.95 MPa, v.c. = 0.22. Among these tests, 30 were carried out on fortified walls (mean compressive strength 2.6 MPa) and 40 on houses (compressive strength 3.2 MPa);
- a total of 40 tests on pisé masonries at Zagora (samples L8 to L11) mean compressive strength 2.96 MPa, v.c. = 0.23. Among these tests, 10 were carried out on fortified walls (mean compressive strength 2.7 MPa) and 30 on houses (compressive strength 3,1 MPa).
- a total of 40 tests on adobe masonries at Zagora (samples M1 to M4) mean compressive strength 2.83 MPa, v.c. = 0.16. Among these tests, 10 were carried out on fortified walls (mean compressive strength 2.1 MPa) and 30 on houses (compressive strength 3.1 MPa).

Fig. 4 – Sclerometer tests. (credits: Rovero L., 2007)

5. CONCLUSIONS

A good earth material suitable to be used as building material in earthen constructions must be doughy and quite rich in clay (more than 20%) because it is just the clay fraction that plays the binding role and gives cohesion to the material. On the contrary a lean earth (poor in clay minerals) displays a low cohesion. Nevertheless the characteristics that a building earth must display depend on the building technique that is used: a quite fat earth (rich in clay minerals) is suitable for adobe and a coarse grained earth with a gravel fraction for pisé (Guillard and Houben, 1989).

In the Drâa valley the most used earth is the so called "garden earth", namely the earth that can be found inside a palm forest. On the contrary the areas outside the palm forest are characterised by a mainly sandy ground which towards the hills becomes stony and it is called " earth of the mountain". Therefore according to the building technique (pisé or adobe) the different earths can be mixed.

The earth utilized as building material in the Drâa valley comes from the surroundings of the building places, taken just under the ploughed layer and selected according to not written rules based on visual and touch examination (colour, consistency etc.). The earth has a great granulometrical variability also in the same site, but yet with a similar mineralogical composition, justified by the fact that it comes from alluvial deposits that display the same minerals although in different amount all along the valley. The comparison of the earth used for pisè and adobe, point out that the earths used for adobe are richer in clay with respect to that for pisè, in agreement with literature data. Nevertheless the earths display low plasticity as evidenced by the classification made according to the two methods most widely used (AASHO and USCS): samples A, B and C are low plasticity silts. This depends by the large amount of framework constituted by quartz and feldspars and by the small amount of expandable clay minerals like smectite which increase plasticity and cohesion but also give rise to shrinkage problems. In summary the earth are quite cohesive and not too expandable, therefore recommended for the construction.

In regards to the adobe bricks in Tamgrout, both the mineralogical and granulometric analyses point out that the old adobe (sample C) is more clayey then the modern one (sample B). Such defects can be explained either with a loss of knowledge in the field of the material culture (meaning that the skill of choosing the best earth has been lost) or due to the working out of the best raw material.

The three adobes compressive strength (sample F, G, H) are relatively different, but there seems to be some direct proportionality between the clay content (see table 1) and the mechanical performance. The adobe of the Tissergat monumental door has a greater compressive strength then the other two new production adobes. On average, adobe have a compressive strength of 2.2 MPa, compatible with the values indicated by the literature (2 -2.5 MPa).

The results of the sclerometric tests performed in Tissergat and Zagora (sample L1 to L11 and M1 to M4), point out that the mean compressive strength of pisé masonries is 2.95 MPa, value close to that reported by the authors as typical for the pisé masonries (3 MPa). Moreover in both villages the compressive strength of the fortified walls is slightly lower than in the houses. A possible explanation is the higher exposition to the atmospheric agents suffered by the fortifications.

The mean compressive strength of the sclerometric tests performed in adobe masonries of Zagora is 2.83 MPa. These data are relatively higher than those obtained from three point bending test, but are completely compatible with them if we refer to the values obtained by a amplifier coefficient, chosen equal to 10, which is generally used. These data demonstrate the great adaptability of the earth to be used as building material.

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Curriculum

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