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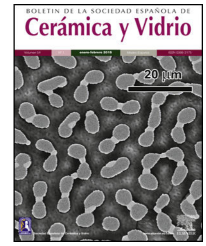

Fabrication and properties of compressed earth brick from local Tunisian raw materials

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ABSTRACT

The housing problem in Tunisia has become more acute due to the high cost of construction materials, thus constituting a source of concern for the population. To resolve the crisis, upgrading abundant local materials has become a necessity. This paper aimed to assess the potential use of Jebel Menchar's geomaterial to develop compressed earth brick (CEB). Laboratory tests were performed to determine the physical, chemical and mineralogical properties. Series of destructive and non-destructive tests were carried out to characterize the properties of bricks based on their composition in terms of compressive strength, flexural strength, water absorption and ultrasonic testing. The results indicated that all of the bricks studied exhibited a compressive strength greater than 2.3 Mpa during the 28-day experiments, thus suggesting a high potential ability to reduce building material problems, while also providing the brick industry a useful and inexpensive new raw material with less CO_2 emissions.

Fabricación y propiedades de los ladrillos de tierra comprimida a partir de materias primas locales tunecinas

Palabras clave:
Ladrillo de tierra comprimida
Fuerza compresiva
Prueba ultrasónica
Fuerza flexible
Absorción de agua

RESUMEN

El problema de la vivienda en Túnez se ha agudizado debido al alto costo de los materiales de construcción, lo que constituye un motivo de preocupación para la población. Para resolver la crisis, la actualización de abundantes materiales locales se ha convertido en una necesidad. Este artículo tuvo como objetivo evaluar el uso potencial del geomaterial de Jebel Menchar para desarrollar ladrillos de tierra comprimida (CEB, por sus siglas en inglés). Se realizaron pruebas de laboratorio para determinar las propiedades físicas, químicas y mineralógicas. Se llevaron a cabo una serie de ensayos destructivos y no destructivos para caracterizar las propiedades de los ladrillos en función de su composición en términos de resistencia a la compresión, resistencia a la flexión, absorción de agua y ensayos ultrasónicos. Los resultados

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indicaron que todos los ladrillos estudiados exhibieron una resistencia a la compresión superior a 2,3 Mpa durante los experimentos de 28 días, lo que sugiere una capacidad de alto potencial para reducir los problemas de los materiales de construcción, al tiempo que proporciona a la industria del ladrillo una nueva materia prima útil y económica con menos emisiones de CO_2.

Introduction

Earth is a noble material which is found in abundance on the built site, hence its widespread use. Earth construction constitutes a major part of the building heritage throughout the world, and is considered as one of the oldest and most widespread construction systems, these techniques have gained much popularity across the world, and it is eco-friendly product [1].

Compressed earth brick technology is primarily focused on providing new housing for the socially and economically poor, and then continues to focus on this concern as its field of application develops. These bricks are unburnt blocks, during production no coal or burning material is needed, compressed earth blocks are an eco-friendly product. This simple construction material, directly derived from the oldest construction traditions of raw earth and baked brick, is able to demonstrate its usefulness and ability adapt to a wide range of economic, technical, architectural, physical, ecological, and social factors [2].

In order to improve the quality and utilization of the compressed earth block through stabilization, suitable additives are used as an alternative to bricks firing. This stabilization can be implemented physically, mechanically or chemically. However, stabilization with binder (Portland cement and lime) seems to be more commonly used to enhance the performance of compressed earth brick. Portland cement, on the other hand, is believed to be the most widely used stabilizing additive, and has been reported to improve the brick's strength and stability [3,4]. In the United States, cement is a popular choice for the stabilization of clay soils [5]. Compressive strength is often considered as the most important mechanical characteristic of construction materials. Several studies carried out on compact soils [6,7], found that their compressive strength ranged from 0.4 to 5 Mpa Atzeni et al. adding stabilizers such as hydraulic cements, hydrated lime and polymers (acrylic latex and an aqueous solution of naphthalene–sulphonate) [8], thus increasing compression resistance from 0.9 (unstabilized) to 5.1 (polymer impregnated). Bahar et al. investigated the development of earth brick with the addition of 10% of cement [9], resistance to compression improved to 4.5 Mpa, and up to 6.5 Mpa with the addition of 20% of cement as stabilizer (compared with the Spanish standard maximum values of 3.6 Mpa with lime and 6.6 Mpa with Portland). Specimen's sizes range widely from 5 cm × 5 cm × 5 cm, 10 cm, 15 cm cubes to 100 cm × 100 cm × 30 cm or 30 cm × 30 cm × 60 cm prisms. After manufacture, the compressed earth blocks acquire more strength while drying. The material reaches a thermodynamic equilibrium when water evaporates. Water content decreases and suction increases when the clay particles get closer because of the increase in capillary forces [10,11]. The water content effect on the CEB mechanical properties has been reported in previous studies. In fact, they have mostly observed lower resistance with higher water content. This is attributed to the decrease in suction when the water content increases. Sand is non-plastic material used like a filler to make the final product durable [12].

The ultrasonic test method is a fast and simple method that can be used to evaluate the characteristics of stabilized soils. This is based on the wave propagation theory, where a sound pulse propagates faster in a dense material and slowly in a porous material. For qualitative characterization of masonry elements, ultrasonic tests are a valid and useful non-destructive method. And it was confirmed as a valid technique for assessing the quality of compressed earth brick, since its response, albeit with certain limitations, was consistent with physical–mechanical properties [13]. Maso et al. [14], who propose ultrasound to assess moisture content and determine Young's modulus, also the ultrasonic test method allows the indirect determination of the intrinsic characteristics of a given sample [15].

This study aims to assess the potential for using geomaterials from Jebel Menchar to develop compressed earth bricks. Samples of sand, red clay and sand clay were used as raw material with a small amount of cement. The main objective of this work is, as a first step, the characterization of the raw material to manufacture raw bricks with high mechanical properties surpassing those of fired brick constructions and analyzed in terms of physical properties: compressive strength and flexion, ultrasonic testing and water absorption.

Experimental

Raw material

The starting materials used for the current research are siliceous sand from Jebel Menchar (SJM) (Fortuna Formation/Superior Oligocene), sand clay from Jebel Menchar (Massiouta Formation) (AJM) (red color), the deposit of jebel Menchar is located about 2 km north of Hammem El Jedidi village and 15 km south of Hammamet City. Sand jebel Menchar is abonded local material how valorization is a necessity to satisfy need people to construction material.

Potter's clays ACBL were taken from Jebel Abderrahmane (Menzel Temime area) located at the Cap Bon (northeast Tunisia) (ACBL).

Table 1 – Chemical compositions of siliceous sands, sand clay of Jebel Menchar and Potters clay of Menzel Temime ACBL.

Chemical composition (wt%)	Siliceous sand	Sand clay	ACBL	Cement
SiO_2	98.505	84.76	49.35	20.59
Al_2O_3	0.237	5.6	20.5	6.62
Fe_2O_3	0.11	2.75	8.74	3.54
MgO	0.071	0.74	2.18	1.39
CaO	0.513	0.38	1.671	61.61
Na_2O	0.031	0.01	0.23	0.13
K_2O	0.09	1.38	2.83	0.61
ZnO	–	–	–	–
Cr_2O_3	–	0.02	–	–
ZrO_2	0.005	–	–	–
TiO_2	0.023	0.41	0.88	–
P_2O_5	0.024	0.09	0.14	–
MnO	–	0.001	0.034	–
LOI	0.39	3.91	13.9	4.18

Fig. 1 – Select sample bricks in vertical position.

A typical local commercial type I 42,5N Portland cement (CEM I 42,5N) that complies with the requirements of specification ASTM C150-04 is used as a testing cement. Its chemical composition is indicated in Table 1.

After sampling, mineralogical analyses were carried out by X-ray diffraction technique (XRD), using Philips X'Pert equipment with a Cu Kα radiation. The chemical composition of powdered samples was determined by X-ray fluorescence, using a Panalytical Axios Dispersive XRF Spectrometer according to the conventional techniques. Tests were carried out according to the NFP94-051standard [16]. IR spectra were recorded in the region 400–4000 cm^{-1} in an EQUINOX model 55 infrared Fourier transform spectrometer, using the KBr pellet technique (about 2 mg of sample and 200 mg of KBr were used in the preparation of the pellets). The particle size distribution of the as-received samples was obtained by laser scattering in aqueous suspension (Mastersizer S. Malvern, England). The Casagrande method, in accordance with the French Standard NF P 94-051, was selected for the determination of the Atterberg limits with an experimental error of ±3%. The plasticity parameters (liquid limit (LL), plastic limit (PL) and plastic index (PI), PI = (LL − PL) were defined by Proust et al., Ancey, Modesto and Bernardin [17]. The specific surface area was determined with the methylene blue index method according to the NFP94-068 [18] standard.

Bricks preparation and characterization

A total of 13 mixtures were prepared to fabricate bricks designated C1, AS1, AS2, SA1, AS2, AS3, SA1C, SA2C, AC4, AC3, AC5, AC6, AC2, AC9 (Fig. 1). The material proportions used in the designs of these mixes given in Table 2, two attempts were made for each mixture.

These designs were further categorized in to three series: Series I, II, and III.

Two mixtures in Series I (C1–SA1) contained only siliceous sand (SJM) and sand clay (AJM) like filler and without addition of hydraulic binder.

Three mixtures in Series II (AS1, AS2, AS3) contained siliceous sand (SJM), sand clay (AJM) and potter clay ACBL. Clay was introduced in to these mixtures to enhance the binding qualities of the bricks.

Eight suggested mixtures in Series III, namely SA1C, SA2C, AC4, AC3, AC5, AC6, AC2, AC9. The manufacture of ecological bricks involves the following steps shown in diagram representative Fig. 2.

In the literature some ranges for the corresponding water content of the compressed earth brick are recommended. In several studies, CRAterre (2012), Jimenez (2007), 5–15% water content. Oliver (1994), 12–19% water content [19]. All mixtures where pressed with roughly 5–10% moisture content, controlled with successive drop tests while adding water to the dry mix.

In order to investigate effect of the cement used like stabilizer on the properties of the compressed earth brick. During manufacturing, the hydraulic binder in the mixture was varied to determine its effect on the strength and consistency of the brick and the amount of water used, the coarse filler fractions consisted of sand. Manual compaction was applied to compressed earth bricks.

Table 2 – Proportion mix of compressed earth bricks.

Trials	Specimens	SJM %	Coarse sand	AJM %	ACBL %	Cement %	Waste glass	Water
Trials 1	C1	30	–	60	–	–	–	10
	SA1	40	–	50	–	–	–	10
Trials 2	AS1	40	–	47	3	–	–	10
	AS2	40	–	40	10	–	–	10
	AS3	40	–	35	15	–	–	10
Trials 3	SA1C	40	–	30	17	3	–	10
	SA2C	40		20	10	10	–	10
	AC4	65	–	–	10	15	–	10
	AC3	30	30	22	–	15	–	10
	AC5	42	33	–	–	15	–	15
	AC6	75	–	–	–	15	–	10
	AC2	53	–	22	–	15	–	10
	AC9	30	–	22	–	15	33	10

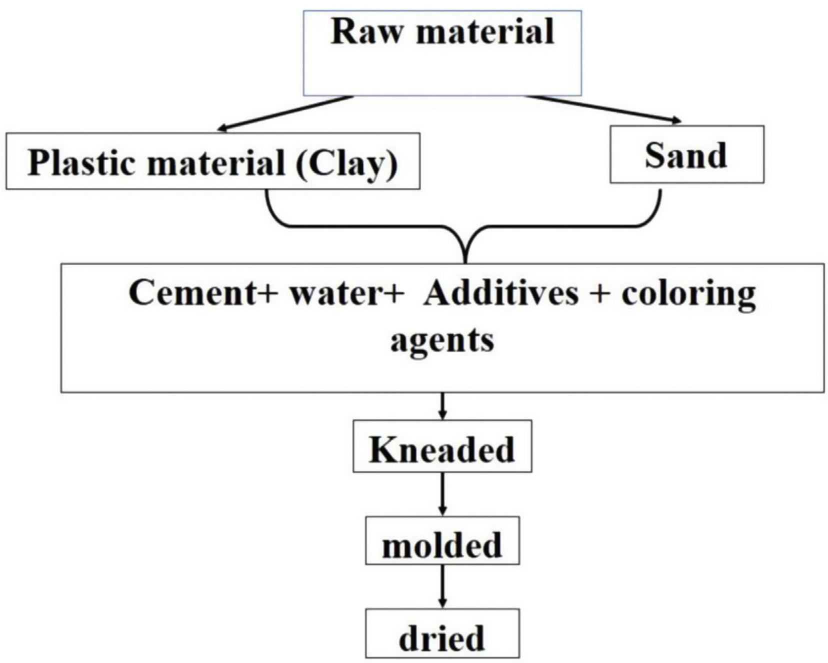

Fig. 2 – Diagram representative of ecological bricks manufacturing.

A parallelepiped mold 4 mm × 4 mm × 16 mm is used in accordance with the format European standards for the mechanical testing of mortar tests for masonry.

In order to control the quality of our unfired bricks, several tests were applied:

The compressive and flexural strengths: The compressive strength of the different brick was tested using a compression/flexural testing E160-01D, 250/15KN Instrument, measured by the Brazilian test with a crosshead speed of 0.5 mm/min according to the Standard EN 1015-11. The value is calculated from the following equation:

$$CS = \frac{F}{S}$$

where CS (MPa) is the compressive strength, F (KN) is the force of breaking specimens and S (cm^2) is the surface area of specimens. At least six specimens were tested for each test condition and an average of the values was then calculated.

The flexural strength of the brick was carried out by the three-point bending method (LLOYD Instrument) applied to parallel epipedic test bars. The rupture strength R was evaluated through the following equation:

$$R = 3.\frac{FL}{2bh^2}$$

where b is length in mm of the test tube, F is breaking stress in N and h is the minimal thickness in mm of the test tube measured after test toward break resistance to traction by flexure is 6 times as weak as resistance to compression. The compressive strength tests were carried out at the National Engineering School of Sfax (ENIS). The samples were tested compressive strength on the seventh and 28th day. The purpose of test done on the seventh day is to observe the condition of the samples on its premature state, as on the 28th day, the sample compressed earth brick can be classified as matured.

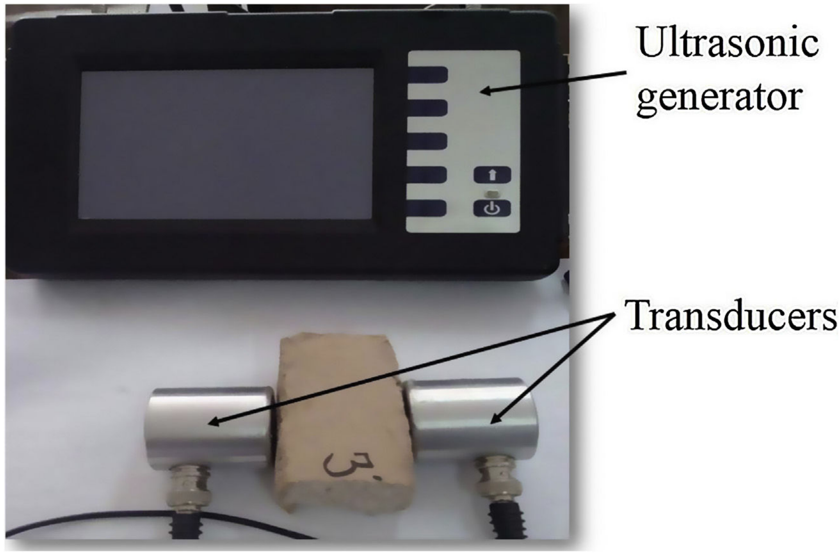

Fig. 3 – Ultrasonic device.

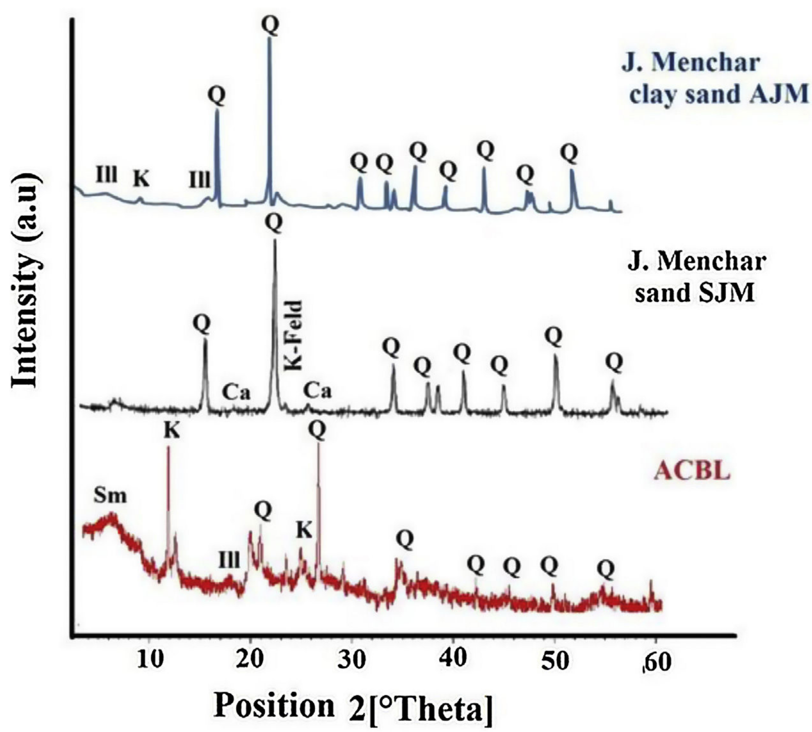

Fig. 4 – X-ray diffraction pattern of Jebel Menchar sand "SJM", clay sand "AJM", of Potters clays "ACBL". Q: quartz; K: kaolinite; III: illite; Sm: smectite; Ca: calcium; K-feld: potassic feldspars.

The water absorption: The water absorption was determined from heated samples according to ISO 10545-3, 1995, fragment after mechanical test at 28 days. The fragments were dried at 105 °C and then weighed, it records the dry mass ms and then put the pieces in water at 120 °C for 3 h and then record the wet mass m h [20,21]. The value of the water absorption (W_A) was obtained as follows:

$$W_A = \left[\frac{W_h - W_s}{W_s}\right] \times 100$$

where W_A is the adsorption of water expressed as percentage; W_h (g) is the mass after absorption test and W_s (g) is the dry mass of the sample [22].

Ultrasonic test: The ultrasonic test is measured by C372N high performance ultrasonic tester (Matest Company) and a set of associated transducer pairs (55 KHz). In this device, time measuring ranges from 0 to 9999.9 μs with a high resolution of 0.1 μs. The sample was placed between the transmitter and the receiver and the faces of the transducers were firmly pressed against the face of the rock samples until a stable velocity is displayed (Fig. 3).

It allows measuring the ultrasonic velocity inside the material since it gives the travel time of the ultrasonic wave (µs) through the sample. The transition time and ultrasonic pulse velocity (m/s) for direct transmission were calculated as follows:

$$V = \frac{L}{T}$$

where V is the pulse velocity (m/s), L is the length of the straight-wave-path through the specimen which corresponds to the distance between transducer faces and T is the transit time (s) [23].

Result and discussion

Raw materials characterization

The chemical compositions of the raw materials determined by X-ray fluorescence are reported in Table 2. The chemical analysis shows that, the sand taken from Jebel Menchar (SJM) essentially consists of silica content was important (around 98.505%), with weak contents of Al_2O_3 and Fe_2O_3 (0.237% and 0.108%, respectively).

The sand clay samples (AJM) is essentially made of SiO_2, Al_2O_3 and iron oxide (84.76%, 5.6% and 2.75%, respectively).

The clay formation samples of Pliocene potters (ACBL) reveals the dominance of SiO_2 (47.85%) and Al_2O_3 (20.50%). The Fe_2O_3 (7.74%) and K_2O (2.83%) attributed to the presence of illitic phase. Further, very low CaO (1.671%) contents correspond to no calcareous clays presented. The loss on fire of these clays is important; it is essentially related to the loss of H_2O from clay minerals on the one hand, and to decarbonation on the other hand.

Fig. 4 shows the XRD patterns of the raw materials preparation of earth bricks. The siliceous sand (SJM) revealed that it is principally formed of quartz (91%) which is pointed out by the presence of the characteristic peaks: 4.25 Å; 3.34 Å; 2.45 Å [24] suggests that the depositional basins were associated with a passive margin [24], potassic feldspars (5%) as the main constituents indicated that the source of these silica sands could be probably of magmatic origin or even metamorphic from the Hoggar Massif [25] and minor proportions of kaolinite (1%) and calcite (3%) were also detected.

The sand clay (AJM) revealed the presence of kaolinite and illite and linking minerals, mainly quartz. This result correlates well with that of the chemical composition.

The X-ray diffractogram of the bulk of clay (ACBL) studied shows that the sample is rich in kaolinite which is associated with some illite, the contents of smectite are present in the form of traces and non-clay mineral (quartz). However, the observation of diffraction peak of the oriented sheets natural clay sample reveals the existence of quartz as the dominant impurity is identified by distinctive reflections at 3.34 Å [26]. Kaolinite, it is represented by basal reflection at 7.1 Å and 3.50 Å consecutively, does not change with ethylene glycol and the collapse of kaolinite structure to an amorphous material takes place on heating to 500 °C and confirms the identification of the mineral (Fig. 5), while illite always remains present under the effect of ethylene glycol or under the heating effect [26].

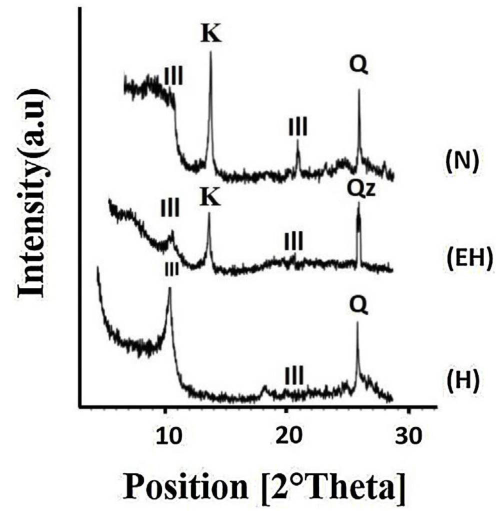

Fig. 5 – XRD patterns of the clay fraction of ACBL; processed with ethylene glycol to orient the sheets and heated at 500 °C. Q: quartz; III: illite; K: kaolinite.

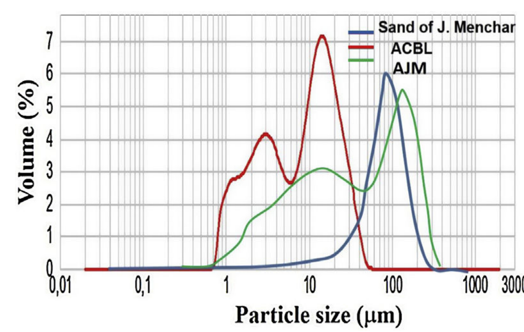

Fig. 6 – Particle-size distribution of Jebel Menchar sand SJM, Potters clay of Menzel Temime (ACBL) and Jebel Menchar clay sand AJM.

Fig. 6 shows particle size distributions of raw materials. The result shows a bimodal distribution of "ACBL" This means that there are two classes of distribution with 3.15 µm, respectively. The "SJM" sand (Menchar) presents a coarser granulometry (approximating 100 µm). The particle size distribution of "AJM" shows a bimodal distribution (10 and 150 µm respectively).

FTIR diagram of "SJM", "ACBL" and "AJM" is presented in Fig. 7. Concerning the IR investigation on Jebel Menchar sand samples (SJM), the spectrum showed bands of kaolinite: 3620.5 cm and 3696.5 cm (O—H stretching vibrations); 989.86 cm (Si—O vibrations); 914.71 cm (Al—OH, bending vibration) and hygroscopic water (1636.78 cm). The spectrum of Potters clays Menzel Temime (ACBL) shows bands of kaolinite: 3620.31 and 3697.8 cm (O—H stretching vibrations); 1005 cm (Si—O vibrations); 911.17 cm (Al—OH, bending vibration) and hygroscopic water (1634. 4 cm). 797.21 cm (quartz doublet vibration) in Fig. 7.

Concerning the IR investigation of "AMJ", the Si—O stretching bands at 1058 cm^{-1} [27] are characteristic of

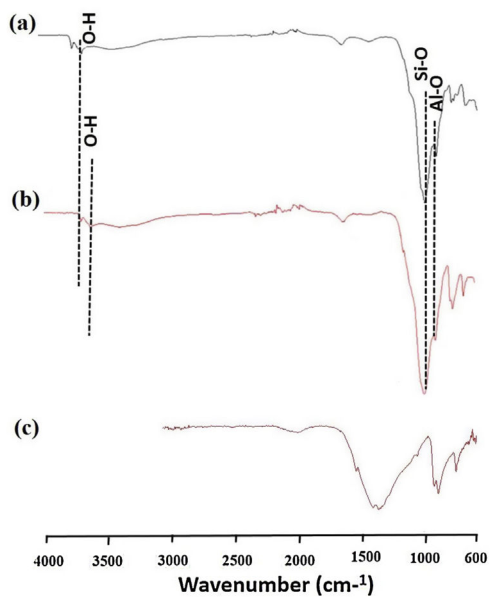

Fig. 7 – IR investigation of Jebel Menchar sand "SJM" (a), Potters clays "ACBL" (b) and clay sand "AJM" (c).

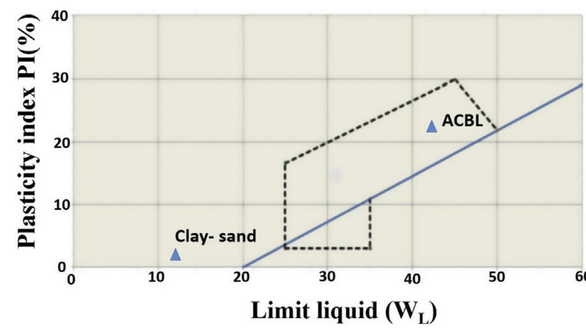

Fig. 8 – Sample position in CRA Terre-EAG diagram.

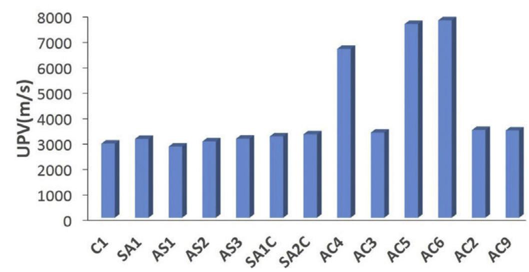

Fig. 9 – Results of ultrasonic pulse velocity.

aluminosilicate minerals. This is in concordance with the high amount of SiO_2 reported by the chemical analysis.

Calcimetry: Identifies the level of calcium carbonate in the sample. This analysis is done using Bernard's calcimeter samples "ACBL", "AJM" and "SJM", have $CaCO_3$ contents of less than 3. Generally, in the manufacture of earth brick, the use of a carbonated clay in small quantity compared to the mixture, is desirable because the carbonates play the role of stabilizing.

By the absorption of the blue methylene molecule we quantified the specific surface area SSA is 130 m^2/g and 7.5 m^2/g respectively, for samples of "ACBL" and "AJM" (Table 3). According to mineralogical analysis, these values can be considered as part of both essential components: specific surface values: illite (100–140) and kaolinite (10–30) as described in the literature [28].

In order to appreciate their suitability for the manufacture of bricks, the liquid limit and plasticity index are presented in the diagram (Fig. 8), defined by the "International Center for Construction in Terre, CRA Terre-EAG" to compare the different materials used for the manufacture of compressed earth blocks. According to the results in Table 3, it can be concluded that the potters' clay of Menzel Temime is more plastic than the sand clay of Jebel Menchar.

Ultrasonic test of the bricks (UPV) was done for 28th days aged samples (Fig. 9). In the first trial when mixing "AMJ" and "SJM" only we see that it represents a weak a low UPV of 2916 m/s, 3100 m/s respectively. Also to the second trial for the compressed earth bricks AS1, AS2, and AS3, had a low UPV of about 3000 m/s with mixing different percent of clay (3, 10 and 15%). Hence the addition of clay has no effect on the UPV test [29]. This can be explained by the higher number of voids [30].

Most of the mixes compressed earth bricks for trial 3 when mixing cement (with different percent 3, 10 and 15%) tested have a higher propagation speed than those made without cement. The content of 5–10% of cement recorded a small increase the UPV values from 3200 m/s to 3280 m/s while content from 10% to 15% of cement shows a remarkable increase of 3439 m/s to 7766 m/s with AC3 and AC6 respectively. This is due to the fact that the curing time progresses and the reactions occur between the soils and the stabilizing agents cement favorite the increases in the stiffness of the soils.

The replacement of a proportion "SJM" by "AMJ" in mixtures AC2, AC9 and AC3 reduces the UPV to half because the addition of a sample, which contains clay, reduces the compactness of the brick unlike the sand even if the brick is stabilized.

UPV measurements demonstrated that the soil stabilized with cement, in most of the mixtures tested, offered a much higher compactness and with regard to mechanical tests. It was found that the ultrasound technique is a complementary non-destructive technique that can be used to qualitatively

Table 3 – Soil properties.

Samples	Specific surface (m^2/g)	% $CaCO_3$	Atterberg limits			
			WL	WP	IP	Nature of raw material
Sand clay of Jebel Menchar	7.5	0	10.29	7	3.29	Non plastic
Potters clay of Menzel Temime ACBL	130	3	44	18.3	25.7	Plastic

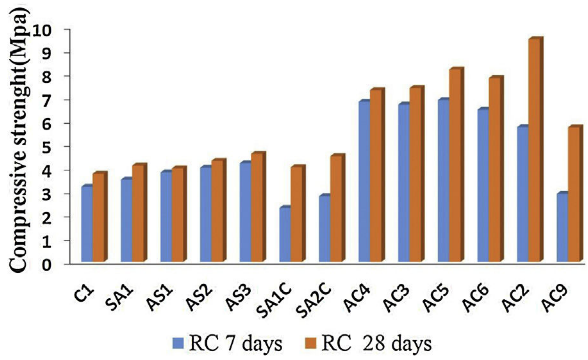

Fig. 10 – Results of compressive strength.

compare the quality of execution of compressed earth brick similar to the work of Jacinto [31].

Compressive strength of brick is important as an indicator of masonry strength and as a result brick strength has become an important requirement in brickwork design [32] and he is become a basic and universally accepted unit of measurement to specify the quality of masonry units test done at 7th and 28th day [33]. The purpose of test done on the seventh day is to observe the condition of the samples on its premature state, as on the 28th day (Fig. 10).

The compressive strength of compressed earth brick (CEB) varies according to the composition of the mixture. As expected, the "CEB" stabilized was superior to the unstabilized CEB, the compressive mixture of trials 3 was 55% superior to trials 1 and trials 2.

The compressive strength values range between 2.3 and 6.89 MPa for all mixes of the seventh day, and between 3.75 and 9.41 MPa of the 28th day, this can be explained by the effect of curing time. The gain of strength in the material is attributed to the chain of reactions occurring between the pozzolans, sand (SJM), sand clay (AJM), potters clay (ACBL) and water (Fig. 10).

The "CEB" is 3.75 and 4.1 MPa was observed for bricks mixed with silica sand "SJM" and clay sand "AJM". The minimum value of compressive strength due to ASTM C129 [34] is 3.50 MPa This work is in agreement with kalifaala [35]. Adobe's dry compressive strength reaches 4 MPa this compressive is high enough to allow safe construction but the wet compressive strength is close to zero. The results show that fine particles do affect quite significantly the mechanical properties.

The ACBL clay was introduced in mixtures SA1, SA2 and SA3, it has not improved the compressive strength also 4 MPa Adding clay as a fine coarse grain that acts as a binder between larger grains did not improve compressive. This work is an accord with Hall and Allinson [36] explain this reason "if soil content contains finer particles than cement particles, this cannot be coated by cement." So more cement is needed to ensure all particles being coated and it becomes uneconomical because it requires a substantial amount of cement than usual. This is proved by Ithnin [37] said that, theoretically, cement can stabilize all the soil. However, experimentally Adam and Agib [38] have shown that the increase of silt and clay content in the soil requires more cement to be added. The initial composition is not suitable for obtaining the required mechanical strength. Stabilization techniques provide for the use of a binder such as cement or lime to strengthen the raw material. The particle size of sand and clay influences the percentage of cement content.

Additions of cement to the raw material with different mixing proportions were carried out, which induced the formation of silicates de calcium hydrates by pozzolanic reactions. In addition, the size of the sand and sandy clay particles helped reactivity to achieve higher strength.

Two samples (SAC1, SAC2) were produced with a wholesale fraction of Jebel Menchar SJM, fine sand Jebel Menchar (too different distribution granulometric) SJM, AJM and a weak percentage of cement did not exceed 3%, the resistance to compression was not improved. A weak proportion of cement does not improve compressive strength whatever the grain seize.

In the other mixtures, the ACBL percentage and cement was increased from 10 to 15%, as indicated. For the 7-day compressive strength test, the highest compressive strength was observed in AC2, AC3, AC4, AC5, AC6. The best compressive strength was observed with AC2 mixtures containing sand clay 22%, sand (SJM) 63% and cements 15%. The results show that fine particles do affect quite significantly the mechanical properties. Furthermore, mixtures containing sand generally have higher compressive strength values than bricks with clay at any age; this could be explained as follows: the sand is generally stronger than clay. Increasing the sand volume may result in an increased compressive strength. The grading of siliceous sand is very important because the void spaces contained by stabilized soil are reduced to a minimum when it is well packed with coarse grained sand filling the interstices with fine grained sand have been shown in previous studies [39]. The compressive strength gain strengthen during drying. The drying conditions control the quality of the brick, because of the pozzolanic reaction in the binder that consolidated the materials progressively. To activate the pozzolanic reaction, water was required; in this study, the content of water was estimated at 10% by weight of admixture. For these results the brick's compressive strength varies in proportion to the percentage of cement. More homogeneous microstructure (smaller pores and absence of micro cracks) can explain these improvements. Two bricks mark a significant rise between the 7th and the 28th day of curing, AC2 (60%) and AC9 (50%).

Best overall engineering properties sand it is suggested that this was due to the quality of bonding with in the composite matrix and the overall homogeneity of the mixture.

Correlation analyzes between the UPV and the compressive strength was carried out in order to define the characterization parameters of the materials used in construction (Fig. 11). A higher propagation speed means a less porous and therefore more resistant medium. This is why the speed is expected to increase for samples with higher force.

Regression analysis establishes the best statistical models by adjust the relationship between dependent variables CS and UPV. The coefficient of determination (R) of this model establishes that the dependent variable CS is predictable at

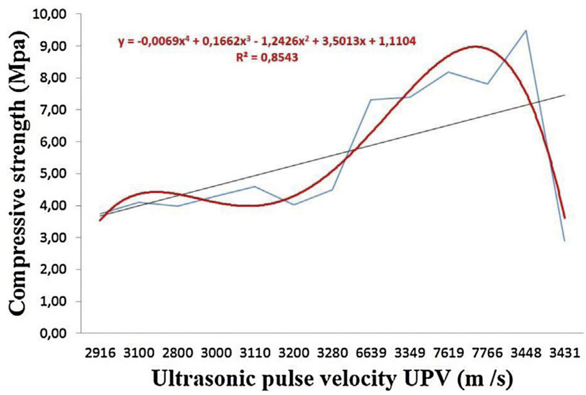

Fig. 11 – Correlation analysis between the UPV and the compressive strength.

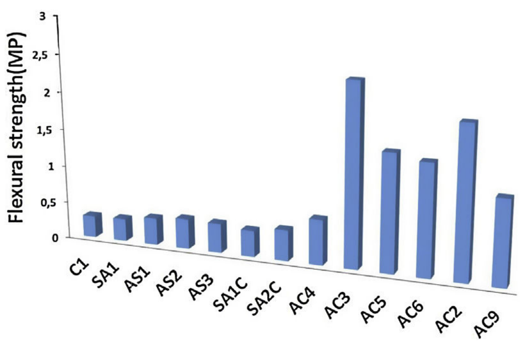

Fig. 12 – Results of flexural strength.

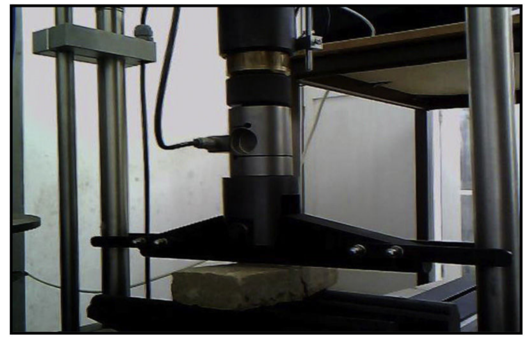

Fig. 13 – Brick under flexural strength.

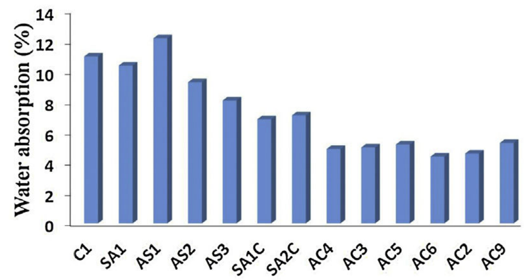

Fig. 14 – Water absorption of different simples.

$R^2 = 0.8543$ and correlation is given by the following equation:

$$y = -0.0069x4 + 0.1662x3 - 1.2426x2 + 3.5013x + 1.1104$$

$$R^2 = 0.8543$$

Flexural strength of compressed earth brick stabilized was superior to the unstabilized CEB, the flexural strength of trials 3 was 23% superior than trials 1 and trials 2 (Fig. 12).

The flexural strength at 28-day values range between 0.29 and 2.4 MPa for all mixes. According to BS 6073 [40] minimum flexural strength described in that is 0.65 MPa for building materials can be used in structural applications.

The brick to which cement has been added as a hydraulic binder is more resistant to bending than that without cement. AS1, AS2, AS3, SA1C, SA2C do not satisfy requirement, but bricks stabilized with cement represent a flexure strength satisfy the standard BS 6073. It is not obvious that bricks exhibiting a high compressive strength generate a high resistance to bending. This is indicated with AC4 compressive strength 6.31 MPa and 0.6 MPa flexural strength (Fig. 13). For AC2, AC3, AC5, AC6, the high compressive strength is proportional to the high flexural strength.

AC6 is mixed with SJM sand 85% and cement 15%, yielding excellent results in terms of compressive strength for the 7 or 28-day period (6.486 Mpa and 7.81 Mpa, respectively), as well as a higher flexural strength 1.469 MPa and a higher speed 0.77 m/s.

UPV is also proportional to the flexural strength. Bricks AC2, AC5, AC6. All results are joined together to prove a good quality of our brick.

Water absorption: Is an important property that influences the durability of compressed earth block as it will determine the material's workability due to the effect of weather. The lower water absorption is the higher resistance to water infiltration and to environmental damage. The highest water absorption is observed for brick unstabilized with cement. The results of water absorption by capillary action revealed a proportional reduction in water absorption with increase in cement content as shown in the figure (Fig. 14). The compressed earth brick has the highest water absorption 12.2% is AS1, whereas the compressed earth brick has the lowest 4.4% is AC6 brick stabilized with cement. According to Kumar [41] the water absorption should not be more than 20%. According to the British standard [42], the water absorption of the brick should be less than 7%. The cement succeeded in inducing hydration in the mixture with water to produce the cementation products required to form hard compressed earth brick.

The relationship between the compressive strength and water absorption test performed on the 28th day, show weak values of resistance to compression recorded on unstabilized samples that were 4 MPa and a high water absorption registered was 11.3%. The compressive strength of brick samples stabilized with 10% cement is affected by the lowest absorption rates 4 and 5% when the compressive strength results are highest 7 and 9 MPa than unstabilized samples.

Conclusions

A novel unfired bricks is promising characteristics product which perfectly meets the current challenges and constraints known in the world of building. The physical, chemical and mineralogical properties were performed. Soil characterization through XRD, IR and particle size distribution tests has proved to be very important in order to understand the different mechanical behavior of the different stabilized soils.

The current study highlighted a major advantage of cement on the stabilization of bricks in terms of mechanical strength and is essential for guaranteeing adequate CEB durability. Also this research analyzed the physico-mechanical properties and their relationship to ultrasound.

To conclude, it can be established that the earth stabilization with cement has a significant influence on the mechanical and physical properties of unfired bricks. Indeed, the compressive and flexural strengths improve with the addition of stabilizers. Also, the compressive strength decreases with increasing clay mineral content.

The compressive strength of the stabilized bricks increases with the stabilizer proportion and the drying age. Compressive strength values reached 9.47 MPa with 15% of cement.

In this research, the use of UPV, has added an interesting additional data set with results which closely align with the mechanical compressive strength results. Non-destructives techniques can be used to qualitatively evaluate and predict the quality of compressed earth brick. Correlation analyzes between the UPV and the compressive strength was carried out in order to define the characterization parameters of the materials used in construction. Also proprieties could even be improved if optimization of the soil mixture is implemented and mechanic compaction done.

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