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Compressive strength behavior of earth blocks stabilized with quarry waste aggregates

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Abstract: Starting from the fact that the exploitation of quarries has serious environmental impacts through their emission of dust and fine sands which are dispersed in nature, and in an ecological and sustainable approach, in this article, we propose a study allowing their recycling and valorization, in the manufacture of earth blocks reconstituted for a possible use in the constructions. The produced samples have been made according to the proportion's addition of (0%, 10%, 20%, 30%, 40% and 50%) with quarries waste aggregates. They were hardened and tested in order to study the influence of these additions on the behavior of the compressive strength. Another formula seeking an optimized mixture according to the compressible packing model where highest resistance was also tested. The results showed that for a substitution greater than the optimized formulation, the compressive strength decreases.

Keywords: Earth block, Crushing sand substitution, Compressive strength, Experimental approach, Compressible stacking model

1. Introduction

Since the 1990s, Tunisia has not escaped the wave of valorization and recycling of waste from the modernization of public services. A law "n ° 96-41, related to waste and the control of its management and elimination was passed on June 10, 1996 **[1]**. One of its main objectives was to encourage the use of materials abundant in nature such as construction and quarry waste. Efficient management of these resources will significantly reduce project.

This article fits perfectly to these objectives. The unexploited blocks of raw earth and more specifically the crushing sands of quarries existing in large volumes constitute a major inconvenience for the professionals and the economy of the country. This often disfigure the natural and rural landscape and damage the environment. Therefore, their valorization in various construction applications is essential. However, current standards exclude their employment in several utilizations.

A great number of researchers have invested in improving the mechanical performance of compacted earth blocks. Either by adding stabilizer like Portland cement, Natural Hydraulic Lime and Hydrated Lime [2], [3] or by adding fibers [4-7]; fly ash [8]; saw dust ash [9] and glass waste [10]. Others have also sought to improve the mechanical characteristics by adding aggregates to the binder mixture [4,6,11-13]. The results obtained by [13] showed that for soils with a low clay and silt content (5 to 10%), the optimum combination of stabilization ensuring optimum strength of 4.1 N / mm2 is obtained for a rate of 7% cement and 3% lime, but the cement stabilizer alone achieved a compressive strength of 3.2 N/mm2. These value remains insufficient for a possible use in load-bearing structural elements. It should be noted that a binding mixture of cement, fly ash, carbon and glass waste have made it possible to achieve resistances in the order of 17MPa [10]. In the rest of the study we retain, the stabilization of the earth material with the Portland cement binder. According to [9], this addition considerably reduces the phenomenon of shrinkage and porosity of the mixture microstructure, thus improving its resistance. For [8,9] the mixture cement-fly ash in the correct proportions often increases the strength by 21 to 147% compared to that obtained by of unstabilized earth blocks. It also densifies the microstructure of the earth regardless of the moisture content.

In an ecological approach, based on previous studies characterizing blocks made with local soil from northern Tunisia, [2,3,14 and 15] stabilized with cement [2, 16] and which has clearly shown its limit in terms of mechanical resistance. We have opted for the minimum investment in the stabilizer and chose the rate of 8% in cement for the manufacturing of earth blocks. This addition is necessary to improve the stabilization of the sandy-gravelly earth skeleton to strengthen ties between the grains [17]. This rate provides a compressive strength of 1 MPa that ensure a minimum of mechanical stability [16,18]. And in a spirit of management and recovery of quarry waste. The fabrication of blocks was done according to 5 formulations including 0%, 10%, 20%, 30%, 40% and 50%) of aggregate addition. We aim at making these blocks convenient for possible massive use in buildings. Moreover, it is well known that the granular skeleton added to a mixture without big size grains develop more its performance. The manufacture of bricks by adding 3 different types of aggregates (limestone, sandstone and porphyry) at different percentages of 0%, 20%, 33%, 43% and 50% was studied by Arsène et al. [11] confirms this well founded and showed a significant improvement not only in compressive strength but also in drying shrinkage and water absorption where they note a considerable reduction. Another study by Serbah et al. [12] further supports this reasoning. By a hydro-mechanical study on dredged sediments, valorized as an eco-geo-material for building construction in the form of compressed earth blocks (CEB), they showed the need to modify the natural sediment with a sand fraction of up to 30% to reach the recommended characteristics in order to be used as CEB.

On unstabilized soils, it is shown [19,20] that the addition of coarse-grained silica sand to the mixture has a harmful effect on the mechanical resistance. According to these authors this decrease in resistance is explained by the matrix weakness due to the decrease in cohesion between the earth and the sand grains. That's why, it will be legitimate to think that the use of a stabilization with cement would have the opposite effect since the forces linking the matrix grains will be stronger.

In this study, the case of substitution by aggregates (0/4), considered as quarry waste, in the preparation of weakly stabilized cemented earth blocks was treated. It is a question of varying the proportions of addition of aggregates and to study its influence on the compressive strength development of the composite. Another formula seeking an optimized mixture according to the compressible packing model was also tested.

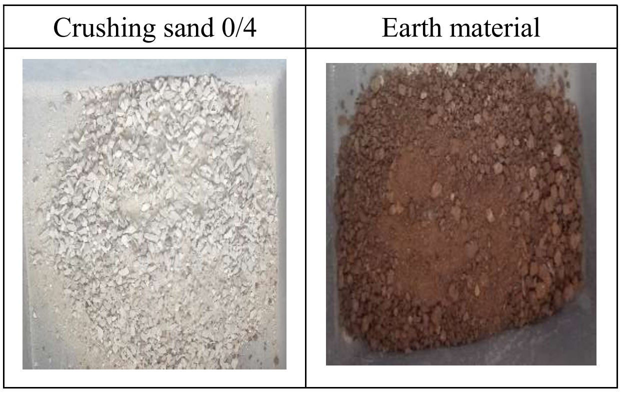
The article begins by identifying the study materials. The selected formulas are also exposed, including the one that offers the optimized mixture. Then, the results of the mechanical compression tests on the different mixtures produced at the different terms of (1,7,14,28 and 365 days) are given. An interpretation is presented. It will assess the contribution of the aggregate's addition on the resistance performance of the stabilized earth. Finally, a theoretical modeling is proposed. It allows the prediction of the compressive strength depending on the rate addition of aggregates and presents modest research attempts to encourage stakeholders like (developers, contractors, the State, individuals, etc.) to enhance, even more, the value of quarry and construction waste in their buildings. Through the work presented, they will find scientific support to justify their use.

2.Material and method

2. 1. Identification of studied materials

The studied materials, Fig. 1, were chosen to align with the country's strategic directions in terms of mineral resources. The raw earth is recommended by the association (Agricultural Development Group). It is extracted from a site found in large quantities in an urban setting in the north of the capital of Tunisia.

The crushing sand, comes from a site close to that from which the raw earth comes. This choice is based on purely economic considerations. The exploited formations belong to the Upper Cretaceous. The operation is carried out by dynamiting the benches, followed by impact crushing.


Crushing sand 0/4

Earth material

Fig. 1: Studied materials

The necessary samples for its characterization or for the mix manufacturing were taken in a single dose. The results obtained on its properties have already been given in reference [2,3,16,20]. They are just recalled here briefly for the purposes of the study. Table 1 gives the sieve analysis of this material. They are obtained by wet sieving in accordance with standard NF EN 933-1 [21].

The results obtained fit well within the limits of the CRATerre [2,18, 19] zone, that justifies its use in bricks and earth mortars. It should be noted that this soil is made up largely of fines (58%). which gives it a fairly significant contribution in the binding phase.

Concerning the crushing sand, the size and fraction's particles of the crushing sand denote a high percentage of fines (19%). For these reasons, its use was not recommended for the preparation of hydraulic and bituminous concrete. According to standard NT 21.30 [22], its cleanliness remains admissible for ordinary concrete (SE> 60).

Table 1: Granularity of materials (in percentage of cumulative sieves according to size)

Opening the sieves (mm)	Raw earth	Crushing sand 0/4
0.08	58.08	19
0.1	63.2	20.2
0.125	66.2	21.16
0.16	69.83	22.32
0.2	77.6	24.28
0.25	84.3	26.6
0.315	89.42	29.18
0.4	92	31.11
0.5	95.5	34.76
0.63	97.44	37.44
0.8	97.7	44.26
1	98.1	47. 34
1.25	98.32	54.03
1.6	98.41	58.31
2	98.55	65.65
2.5	98.65	75.75
3.15	98.77	79.48
4	98.9	85.23
5	99.01	95.77
6.3	99.25	100
8	100	

Regarding cement, our choice was for the CEM II / A-L 32.5. It is the hydraulic binder that is the most marketed in Tunisia and often used for masonry work and large-scale work. It is a Portland cement composed of limestone (CEM II). According to standard NF EN 197-1 [23], Its granularity is shown in Fig. 2. [24. page89]

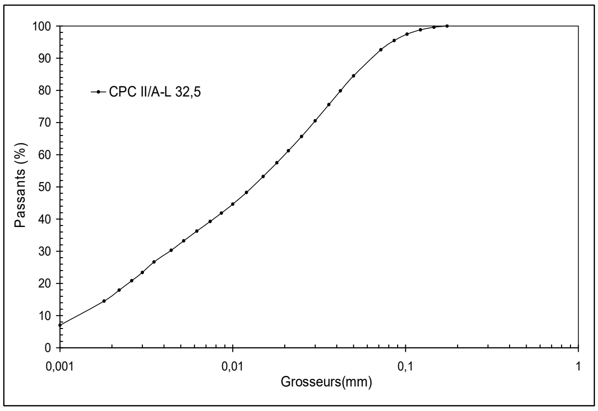


Fig. 2: Particle size distribution curve of CEM II / A-L 32.5 cement

Other results of the characterization tests carried out according to the standards are summarized in Table 2. The real density, the porosity (n), the plasticity index (PI), the equivalent of sand (SE) and the chemical composition

Table 2: Materials properties

Properties	Studied materials		
	Raw earth	Crushing sand 0/4	Cement CEM II AL 32.5
Real density (t/m3)	2.4	2.63	3.19
< 80mm (%)	58.08	19	94.5
n (%)	56	1115	-
PI(%)	7	8	-
SE	54	65	
Chemical composition (%)	SiO2(52.15). Al2O3(6.71). Fe2O3(3.36). CaO(16.92). MgO(0.92). Na2O(0.16). K2O(0.92). SO3(<0.01). PF(17.55)	SiO2(6.55). Al2O3(3.71). Fe2O3(1.03). CaO(61.32). MgO(0.92). Na2O(0.04). K2O(0.44). SO3(<0.01). PF(34.28)	C3S(7017). C2S(31.1). C3A(2.2). C4AF(12.8). Gypsum (5.9). Limestone filler (5.2)

For real density, it is much lower than that of common granular products (2.5 t / m3) this is mainly due to its high porosity. According to the Atterberg limit results, the study soil is classified as low plastic silt. Its cleanliness is more or less acceptable for possible use in cement mortars [19,20]. Its chemical composition marks a dominance of silica SiO_2 (Quartz) and to a lesser degree of calcite (limestone) and a weak presence of iron Fe_2O_3, which leaves material fragile.

The crushing sand is characterized by the dominant presence of limestone in its rock (61.32%).

2.2. Samples preparation

The preparation of the samples is prepared by substituting a portion of the raw earth (0%, 10%, 20%, 30%, 40% and 50%) with the crushing sand. Another F_{opt} mixture also interested our study. It is about finding the granular pile-up (earth / sand) which makes the mixture the most compact, by the mean of the compressible packing method [24,25] using BétonLab software, based on a homogenization calculation and taking into account the limited applied maximum compactness of the granular skeleton.

The optimum gives the following proportions: 68% earth and 32% sand. Thus 7 mixtures were formulated.

In the second step, each composite was dry mixed with the cement stabilizer at the rate of 8%. According to [26], such a choice is justified by the fact that it already gives acceptable resistance, in an ecological approach of constructions.

After mixing, each mixture was moistened. The water amount added is that which makes it possible to obtain a homogeneous mixture of firm consistency (Slump Test value A less than 4 cm). The third step is to put the prepared mixture in a 7x7x28 cm^3 molds Fig.3.

Fig. 3: Instrumentation and mold (7x7x28) preparation

Then the mixture is compacted using a hydraulic press at a constant pressure of 10KPa. which is the value used for the conventional LCPC test [25] for the measurement of compactness. No weathering was observed.

All the prepared formulas (F0. F10. F20. F30. F40. F50 and F_{opt}) are finally placed in a humid chamber. Fig. 4. with relative humidity above 80% and at a temperature close to 20 ° C. Table 3 summarizes the dosage of the constituents of each mixture as well as their properties.

Fig. 4: Moist chamber for conservation of earth blocks.

3. Results of the compression tests

Uniaxial compression tests using an electronic universal testing machine Fig. 5 were made on samples from cubic shape $7x7x28cm^3$ at different terms: 1; 3; 7; 14; 28; and 365 days from the date of specimens manufacturing for the seven formulas tested.

Fig. 5: Electronic universal testing machine

The results found are shown in Fig. 6.

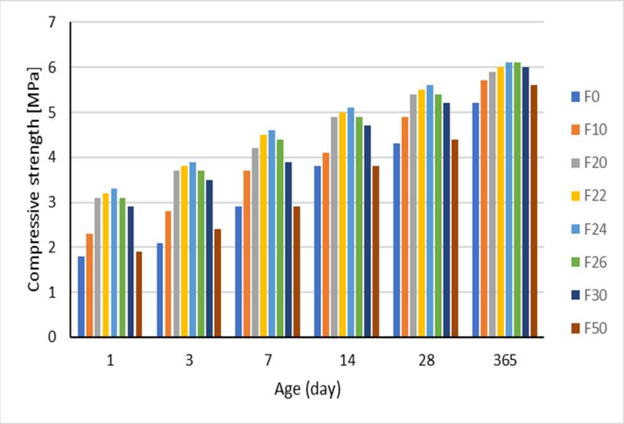


Fig. 6: Development of compressive strength depending on time at different sand substitution ratios.

It is quite clear that the compressive strength evolution of formulated earth blocks increases proportionally with the sand addition up to the optimal formula (24%) then it decreases and the sand addition becomes harmful.

We join thereby the set of interpretations made in the literature [11,20]. At a well-determined rate of grain particles. greater than 63µm. the mixture may well be destabilized and it loses compactness. which makes it more fragile.

The increase in the granular skeleton is not always beneficial in increasing the mechanical properties of earth blocks.

It has been approved in previous studies. such as those done by [2] and [16]. that porosity has an important role on the resistance behavior of the earth compacted blocks. They give the following expression:

$$R_c = 83.27e^{0.12n} \qquad (1)$$

According to these studies. the compressive strength decreases when the porosity of composite mixtures (without cement) exceeds 35%.

In this study the compressive strength. that correspond to the formula Fop of 24% substitution ratio. reach the value of 5.6 MPa and decreases. The addition of the granular skeleton beyond this optimum reduces the adhesion between earth paste phases and aggregate phases. It is due to the low added cement percentage in the mixture.

Table 3: Ration constituents of the formulas tested

		Dosage				Properties	
Formulation	Earth material (kg/m3)	Lime sand 0/4 (Kg/m3)	Cement (kg/m3)	Water (kg/m3)	RVM (kg/m3)	Slump Test value (cm)	Porosity (%)
F0	1550	0	124	301	1975	4	30
F10	1380	138	110.4	288	1916.4	3.6	24
F20	1480	296	118.4	330	2224.4	3.9	22
F22	1320	325	112.6	316	2230.2	3.8	21.6
F26	1360	355	111.2	326	2232.7	3.8	1817
F30	1386	415.8	110.88	325	2237.68	3.7	19
F40	1260	504	100.8	318	218218	3.8	17
F50	1240	620	991.2	336	229512	3.6	15
Fopt	1420	438.4	112.6	338	2256	3173	18.3

According to [17]. as the earth is containing a high percentage of the gravel. it needed more cement. However. it presents at a well-determined rate of substitution. close to that allowing to offer an optimized composite mixture. a considerable gain in strength: an increase of 30%. which gives it the possibility of being accepted in several uses of construction.

It should be remembered that the composite strength is always controlled by the weakest link between earth paste and aggregates. In the most frequent cases. the transition phase is the most fragile. The presence of cement at very low rates like that used in this study would be interesting to increase them in order to increase the compressive strength.

4. Modeling

As it turned out that the compressive strength Rc of stabilized earth blocks at different crushing sand is function of the sand substitution ratio. It is perfectly lawful to relate these two parameters. Fig. 7 gives the variation of compressive strengths as a function of percentage substitution at the 28th day.

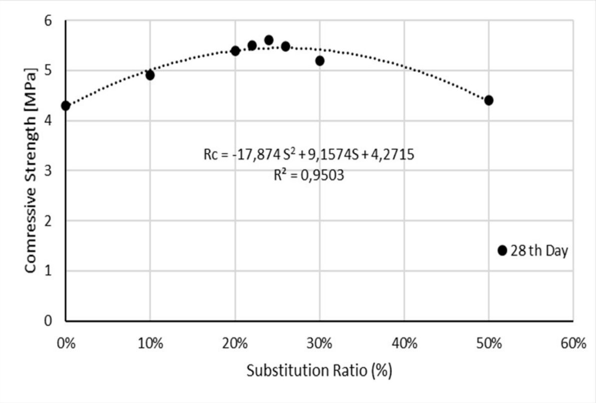


Fig. 7: Variation of compressive strength as a function as substitution ratio

It indicates that this variation obeys to the parabolic law (2):

$$R_c = -17.874\%S^2 + 9.1574\%S + 4.271 \quad (2)$$

and shows a good correlation: R^2=0.9503. and show that Fop correspond at 24% substitution rate and gives the optimum compressive strength value about 5.6 MPa.

The correlation coefficient (R^2 = 0.9503) justifies the result efficiency. In reverse. this approach makes it possible to predict the optimum substitution rate in crushing sand allowing the maximum gain in compressive strength. However. note that even for different ages the same shape of the curve is preserved with obviously different coefficients.

5.Conclusion

The exploitation of earth blocks and quarry wastes such as crushing sands in constructions are nowadays an urgent necessity. against the environment protection and the sustainable development of the country.

This experimental study allowed us to develop these kinds of natural resources found in large quantities in nature. It has shown that for a substitution rate of crushing sand for earth stabilized blocks at 8% cement. increase the compressive strength. which favors its use in various engineering civil work applications. The optimum ratio is the only one that provides the optimum mix. In practice. it suffices to optimize the granular skeleton of the raw earth with the crushing sand to determine its value. The equation (2) given will also make it possible to predict this ratio.

This work provides new data which will better help to exploit and save these granular resources intended for the manufacture of the hydraulic mixtures of tomorrow.

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