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Experimental Study of the Formulation of Mortar Based on Silty Sand of Togo

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Abstract This study consists in experimentally determining a formula of mortar got from silty sands of Togo for the purpose of optimal mechanical properties. 1,443 4cmx4cmx16cm test tubes of mortars made from silty sands of 12 sites of extraction of Togo are prepared at variations of water and cement. The results show that for the water-cement ratio (E/C) of 0.5, the evolution of resistances in compression at 28 days of age (σ_c) increases exponentially to C/S and E/S ratios ranging between 0.311 to 0.512 and 0.156 to 0.256 (σ_c=ae$^{b1(C/S)}$=ae$^{b2(E/S)}$ with 0.061<a<0.182, 11.08<b1<12.9 and 22.17<b2<25.80). They become stationary beyond these values (σ_c≈19MPa to 35,45MPa). Two formulas of rich mortars (E/C=0.5, C/S>0.512 and E/S>0.226) and lean (E/C=0.5, C/S<0.311 and E/S<0.156) silty sands taken in Togo are therefore defined.

Keywords: *silty sand, mortar, Togo, mechanical properties*

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1. Introduction

In Togo like in many other African countries, there arevarious types of sands: sea sands, river sands, sands from rocks crushing and continental dunes. For a long time, in order to meet the need for sands in Lomé and its surrounding areas the littoral sands are often used, whereas in the inner parts of the country only the sands of the riverbeds or the continental dunes are used. Since 2011, due to the devastating coast erosion, Togolese government banned by an inter-ministerial order n°031/MME/MERF of 5 Mai 2011, the use of the littoral sand in the interest of protecting the littoral against the erosion. The constructors had therefore no choice but the use of the sand inside the country. Thus, many extraction sites are born in the southern part of Togo in addition to the already existing ones inside the country.

The sands of the Togolese dunes, mostly made up of silice (silty sand), are generally medium-sized (Mf~2.656) and very clean (ES~100>80), therefore, much suitable for qualitative concrete [1,2]. As for silty sands, they contain in addition to cley or alumina, quartz, feldspath, magnetic and Limon composed of disaggregated quartz with grains lower than 0.05mm. These silty sands are generally fine (Mf~1.966), of the category «f3», of granular class 0/1 (d~0.08mm), poorly graduated (SP), of tight granulometry, very badly classified (Si~9.119), of strong asymmetry toward small sizes (Sk~0.451), and lightly cleyed (ES~66.32). They are therefore generally not fit like granulat for classic concrete [3].

Good compressive strength is the performance often sought for hardened mortar. This performance depends on a number of parameters including the type and dosage of cement, the porosity of the mortar, the dosage of water and cement.

Among the formulas that make it possible to predict the resistances, that of Féret is the best known one and is also function of dosage of cement, water, the volume of air in the mortar and a coefficient K according to the class of cement, the type of aggregates and the method of implementation of the concrete. The knowledge of this parameter K is not known for the sands of Togo, the application of the formulation of Féret becomes impossible or difficult.

This work consists in experimentally researching a formulation of mortar based on silty sands of Togo enabling to have resistances in optimal compression. Which will allow to have a mortar formula for the production of coatings, cobble-stones, stonework, etc. in the construction works.

2. Materials and Methods

2.1. Materials

The following raw materials and the material are used for the study:

- silty sands from twelve (12) sites of extraction of sand in Togo (Figure 1)
- a motor mini-mixer (Figure 2)
- an electronic scales of the brand SILVERCREST, with a maximal charge of 5,000g and precision of 1g;
- a machine used for shaking up test tubes of the brand LABOTEST of 90 cycles in 30 seconds with an automatic stop (Figure 2)
- a vat with a temperature of 105°C for the conservation of sands and lands;
- an equivalent device of sand;
- a series of sieves AFNOR with opening (mm):0.08-0. 1-0. 125 -0. 16-0.2-0.25-0.315- 0.4-0.5-0.63-0.8-1-1.25-1.6 and 2;
- prismatic mould of 4cmx4cmx16cm (Figure 2);
- a mini-press device of the brand PERIER, with maximal charge of 300kN and precision of 0.5kN with cells of compression and bending (Figure 3);
- water vat for the conservation of test tubes:
- a transparent tube and a graduated test tube for measuring of absolute density

2.2. Methods

Samples of sand from 12 sites (Aképé-Idavé, Sessaro, Tchamba, Bavelem-Poyo, Aouda1, Aouda2, Wolo-Afem, Agbandi1, Agbandi2, Kpei-solongo, Fazao, Bovoulem-Poyo1, Bovoulem-Poyo2 (Figure 1) underwent identification tests according to AFNOR standards [4,5,6,7,8]. The fineness module (Mf) is then calculated from the following formula [1,2,8]:

$$Mf = \begin{pmatrix} Q_r(0.125) + Q_r(0.25) \\ +Q_r(0.5) + Q_r(1) + Q_r(2) + Q_r(4) \end{pmatrix} / 100 \quad (1)$$

Qr(x) is the cumulative distribution at the opening sieve *x*.

The performed tests are the equivalent of sand, the densities and the granulometric.

For the research of formulation, according to AFNOR standard [9], the dosage of 1,350g of sand, 450g of cement and 225g of water is exploited by keeping unchanged the dosage in sand and by varying that of cement from 420g to 490g and water from 200g to 290g at paces of 5g. Each of the 315 resulted dosages is kneaded in a mortar mini-mixer (figure 2) and then moulded in the 4cmx4cmx16cm mould, and vibrated with jolting device (Figure 2). The gained products, freed from mould after 24h are kept in a water vat at a temperature of 20°. After 28 days of age, the 945 (315x3) test tubes had been broken up into two by bending and each half-test tube underwent the crushing with the press of the brand PERIER (Figure 1) for determining compression resistances, that is 1,890 half-test tubes.

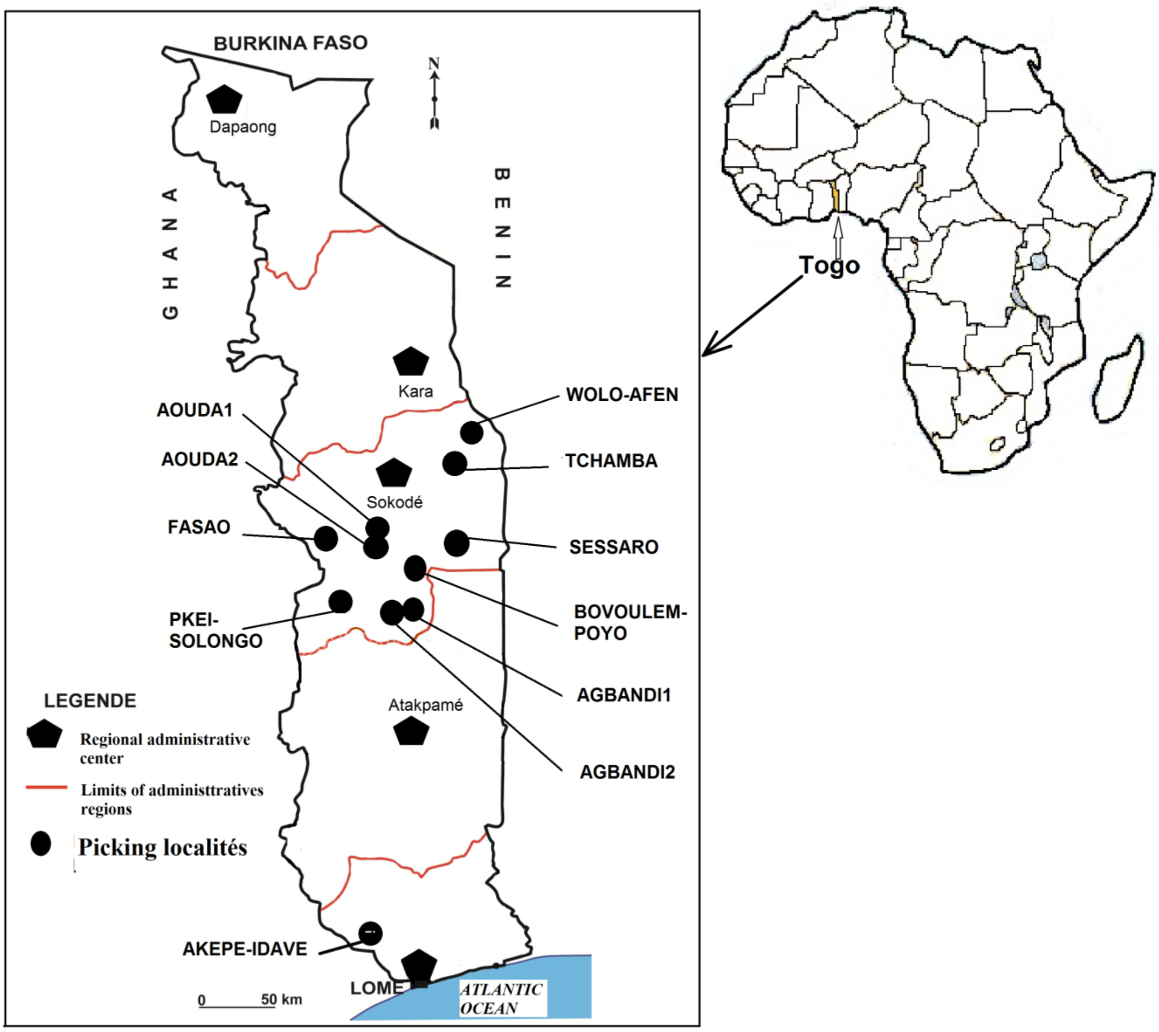

Figure 1. Geographical location of Togo and zones of samples

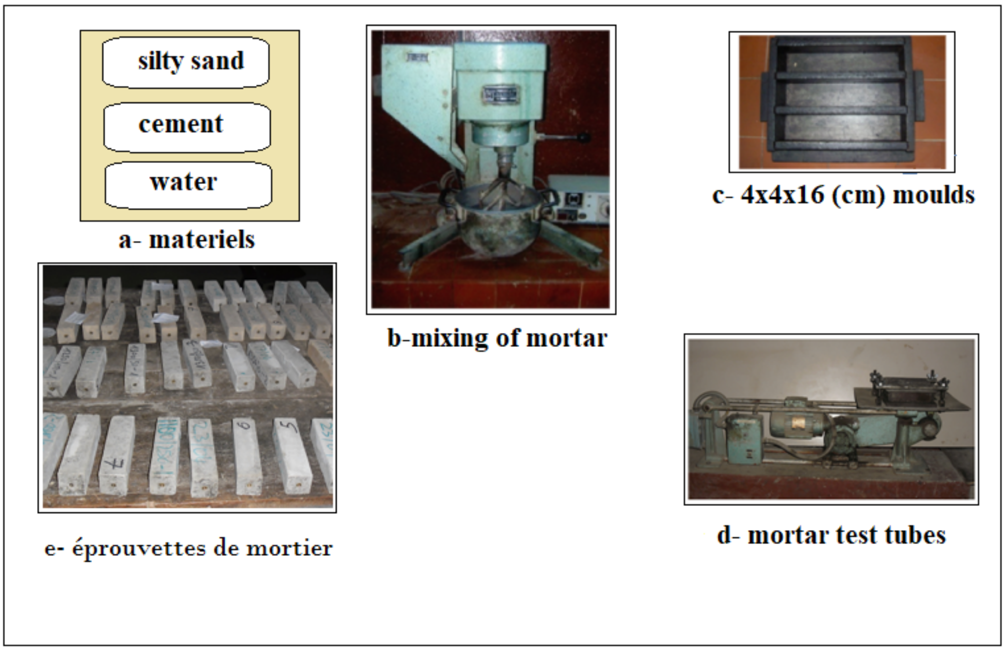

Figure 2. Experimental device for the preparation of test tubes

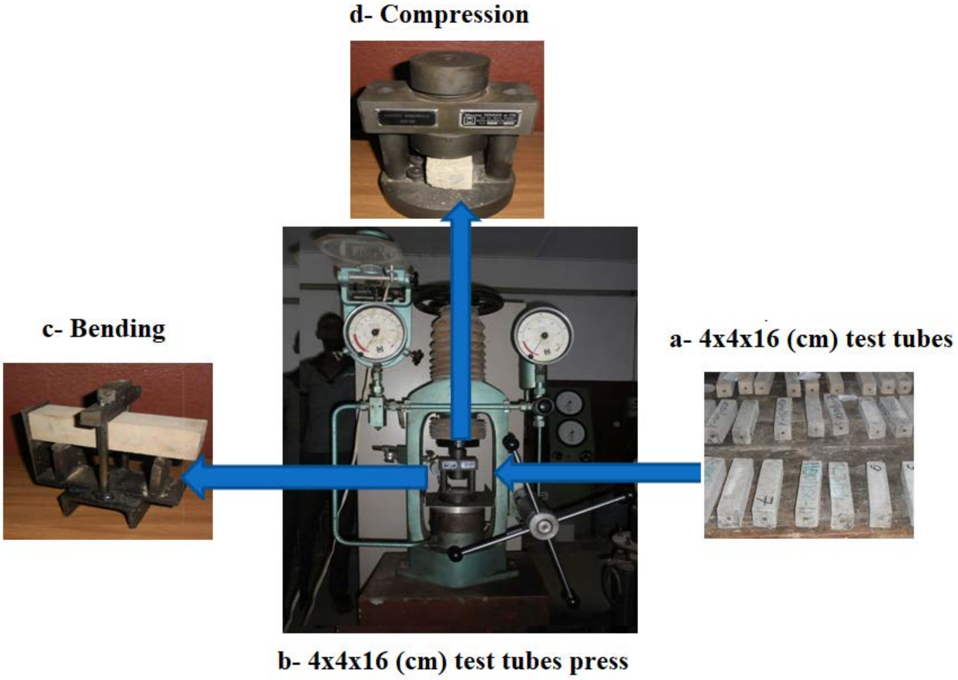

Figure 3. Experimental device for determining mechanical properties

The proportion of water and cement (E/C) providing an optimum dosage has been used to categorize the dosages of mortars made up of silty sand of Togo. For this stage of the work, the dosage in sand of 1,350 g is kept constant whereas that of cement has varied from 100g to 1,000g at rates of 20 g and water of 50g to 500g at rates of 10g, by maintaining the proportion E/C constant on cement. The resulting 46 mixings correspond to 138 test tubes underwent the same preparations, conservations and crushings as previously. Thus, 138 test tubes are subjected to the bending test and 276 half-test tubes to the compression test.

Other samples (360) obtained with a dosage in sand of 1,350g and cement varying from 100g to 1,000g at rates of 80g and water of 50g to 500g at rates of 40g by maintaining the proportion w/c on constant cement underwent the conservations and crushings (360 in bending and 720 in compression).

The 4cmx4cmx16cm test tubes are subjected to the three points of bending test (Figure 3); the halves of the half-test tubes obtained are subjected to compression resistance test on 4cmx4cm surfaces; the break-up strength at the compression is measured.

By considering the test tubes whose charged faces are square at end «α», the expression of the constraint (σ_c) is provided by:

$$\sigma_c = \frac{P}{a^2}. \quad (2)$$

The envelope spindle is the limit zone in which measuring results may vary. The expressions of limits of the spindle are provided by:

$$\begin{cases} X_f = X - 2\sigma \\ X_s = X + 2\sigma \end{cases} \quad (3a)$$

In these equations, X_f and X_s are specific values lower and higher respectively; X the average of measures; and σ the typical gap of measures, provided by the following equation (3b):

$$\sigma = \frac{\sum_{1}^{N}(X_i - X)^2}{N-1} \quad (3b)$$

Where by X_i indicates the measured data at rank *i* and *N* the number of samples.

3. Results

Table 1 and Figure 4 show identification results of materials.

The results show that 67% of the silty sands representing subject of study have been very fine (Mf<2.1) and 50% are not clean (ES<70). So, the sands are generally unfit to be used as granulates for classic concretes, but they are used for concretes whose easy implementation is in great demand. This behavior is conform to that of silty sand of Togo taken as a whole [3]. Consequently, it is very different from that of the littoral sand of Togo which is more suited to concrete works [1,2].

Figure 5 provides the results of resistances in compression according to dosages in water. These charts show that for a dosage in constant cement, resistance always presents an extrema.

Table 1. Characteristics of silty sands and sands from Togo

Types of sands	Fineness module Mf	Sand equivalent ES	Aapparent density d_{ap}	Absolute density d_{ab}
Tchamba's sand	2.098	90.660	1.380	2.65
Sessaro's sand	3.380	93.000	1.530	2.69
Wolo-Afem's sand	2.058	86.660	1.430	2.63
Aouda1's sand	1.448	68.660	1.350	2.65
Aouda2's sand	2.500	63.660	1.350	2.62
Pkei-Solongo's sand	1.895	90.660	1.430	2.69
Bevelem-Poyo's sand	0.980	63.330	1.330	*
Fasao's sand	1.520	72.660	1.350	2.62
Agbandi1's sand	2.695	53.000	1.500	2.57
Agbandi2's sand	1.668	79.660	1.380	*
Bovoulem-Poyo's sand	2.580	63.330	1.330	2.60
Aképé-Idavé's sand	1.800	54.490	1.600	2.64
Average of studied silty sands	**2.052**	**73.314**	**1.413**	
Silty sand of Togo (Amey, 2014)	1.966	66.32	1.5	2.72
Silty sand of Togo (Amey, 2006)	2.656	100	1.55	2.65

*Non accomplished tests.

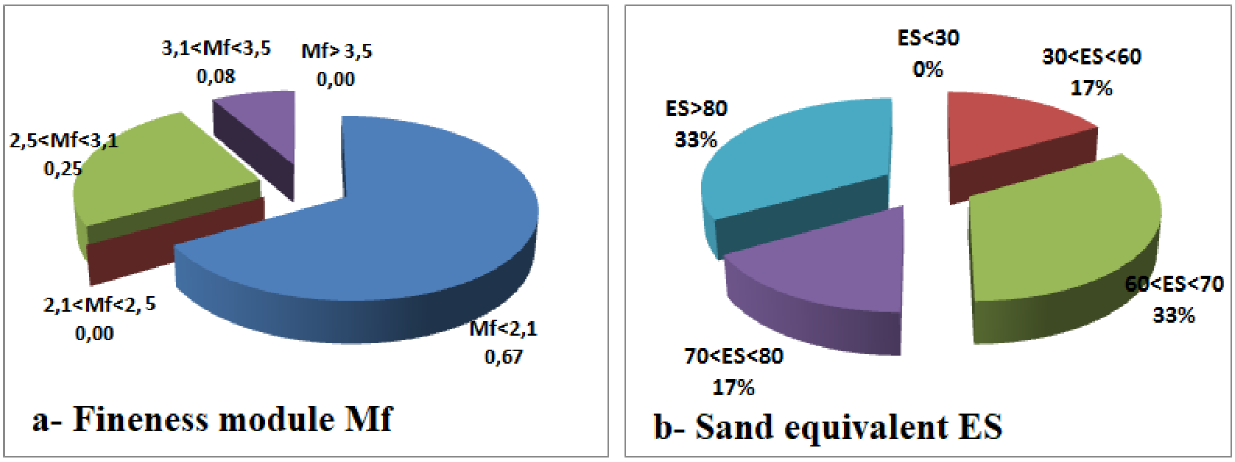

Figure 4. Distribution of the module of fineness and the equivalent of sand according to qualities of silty sands

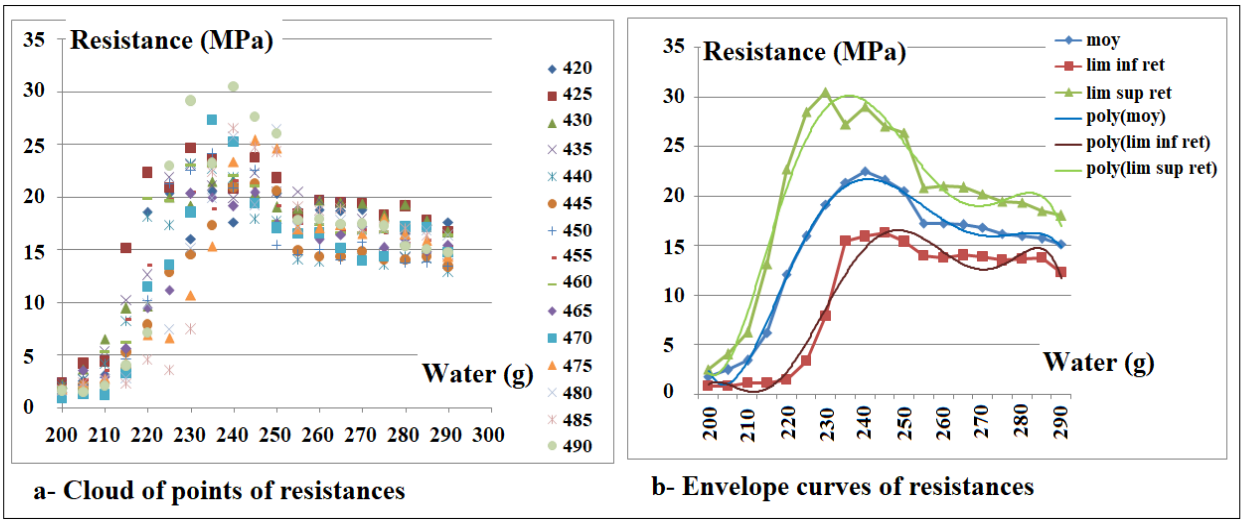

Figure 5. Resistances in compression according to dosage in water for dosages in cement of 420g to 490g (silty sand of Aképé Idavé)

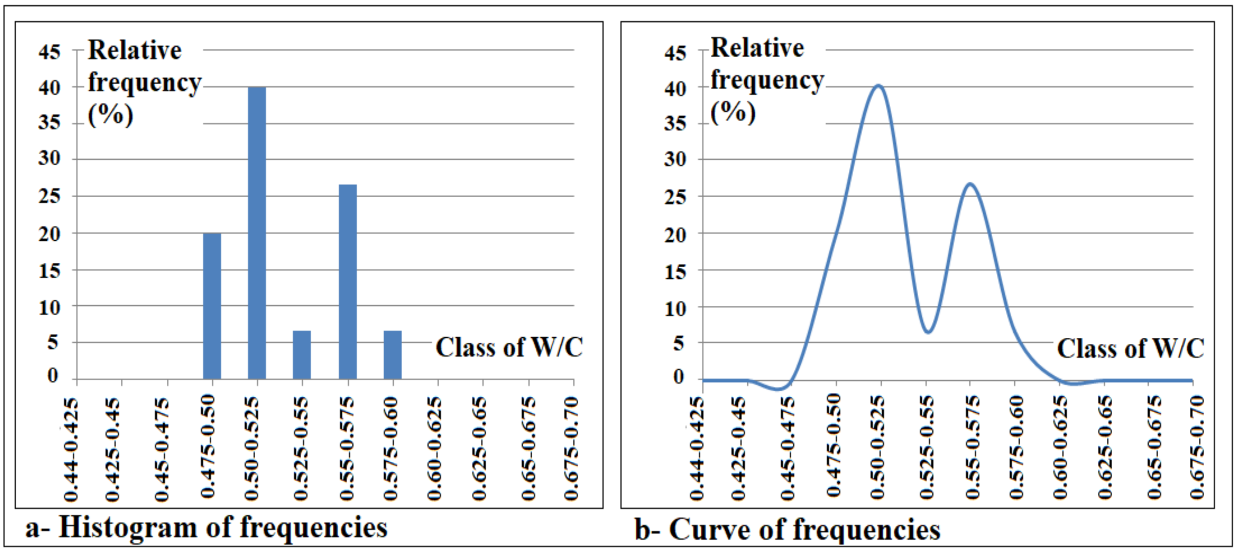

Figure 6. Frequences of appearance of maxima resistance for E/C (silty sand of Aképé Idavé)

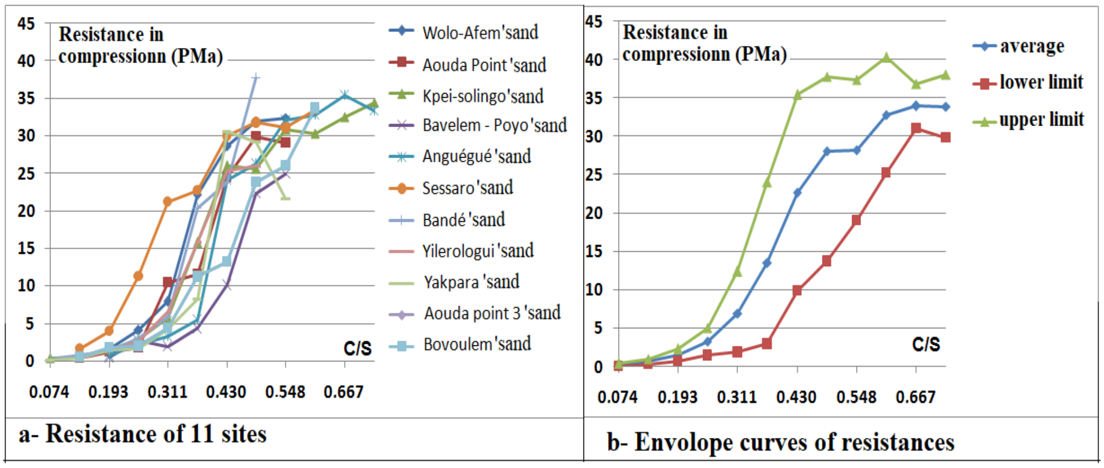

Figure 7. Resistances in compression according to C/S from 11 sites of silty sands

The extrema extracted from Figure 5 and classified results in a histogram of the Figure 6 that presents the percentage of appearance of a proportion E/C corresponding to optimal resistances.

Figure 6 shows that no maximal resistance has appeared in the E/C intervals between 0.40 and 0.475 and between 0.60 and 0.70. The maximal resistances are therefore appeared for proportions E/C in the interval [0.50; 06[.

Thus, the value E/C = 0.5 will be used in search for proportions C/S and E/S providing optimal resistances

Figure 7 to 10 provide for W/C = 0.5 the evolution of resistances in compression and bending according to proportions C/S and W/S for the various sand under study. The charts show that resistances increase and tend to take up a stationary speed.

The analysis of the results of sands of Aképé Idavé (Figure 8), and the equations obtained from these experimentations and the coefficients of determination are provided by:

$$\sigma_c = 0.104e^{16.08(C/S)} \text{ and } R^2 = 0.985 \quad \text{for } C/S \le 0.320 \qquad (4a)$$

$$\sigma_c = 0.104e^{32.17(E/S)} \text{ and } R^2 = 0.985 \quad \text{for } E/S \le 0.175 \qquad (4b)$$

$$\sigma_c = 0.88 ln\left(\frac{C}{S}\right) + 19.32 \text{ and } R^2 = 0.015 \quad \text{for } C/S \ge 0.320 \qquad (4c)$$

$$\sigma_c = 0.88 ln\left(\frac{E}{S}\right) + 19.93 \text{ and } R^2 = 0.015 \quad \text{for } E/S \ge 0.175. \qquad (4d)$$

We may therefore say by looking at these equations that the resistances exponentially rise and become stationary in a logarithmic way according to the proportion E/S or C/S.

The determination of tending curves from envelopes curves (Figure 7b), in the zone C/S<0.320 and E/C<0.175 growing exponentially, enables to obtain the spindle as showed in Figure 9. The equations of the curves in the logarithmic zone can be taken for a strait because of their increasing rate that is quite negligible. We therefore get a margin of spindle providing lower and upper limits of resistances the silty sands of Togo can have (Figure 10).

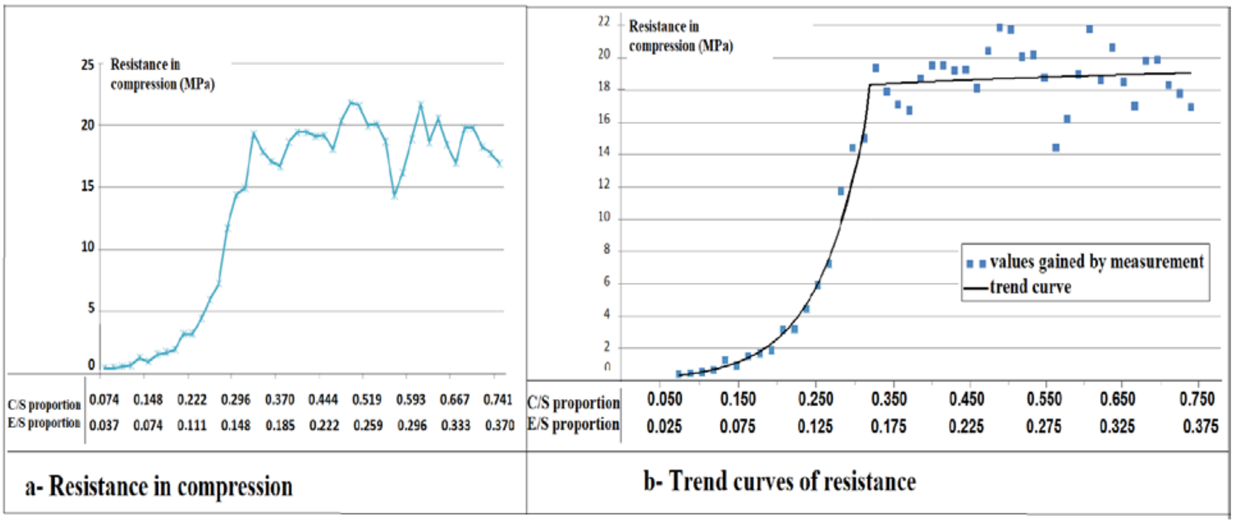

Figure 8. Resistances in compression according to C/S and E/C of silty sands of AképéIdavé

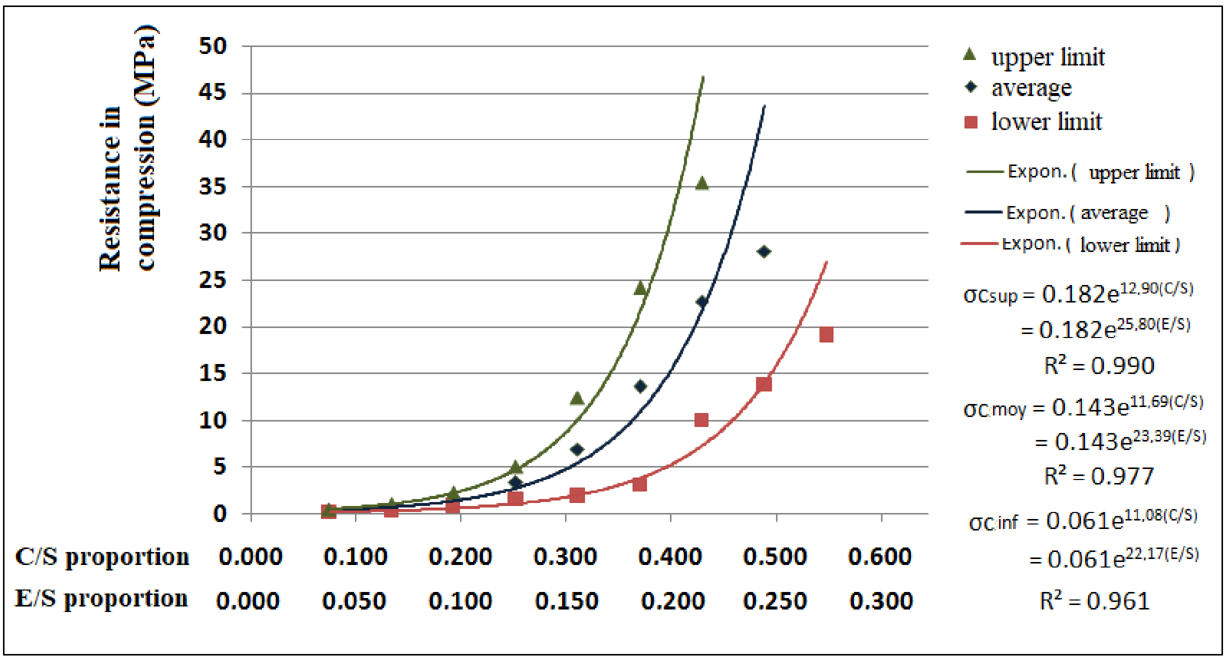

Figure 9. Envelopes curves of resistances in compression for E/C =0.5

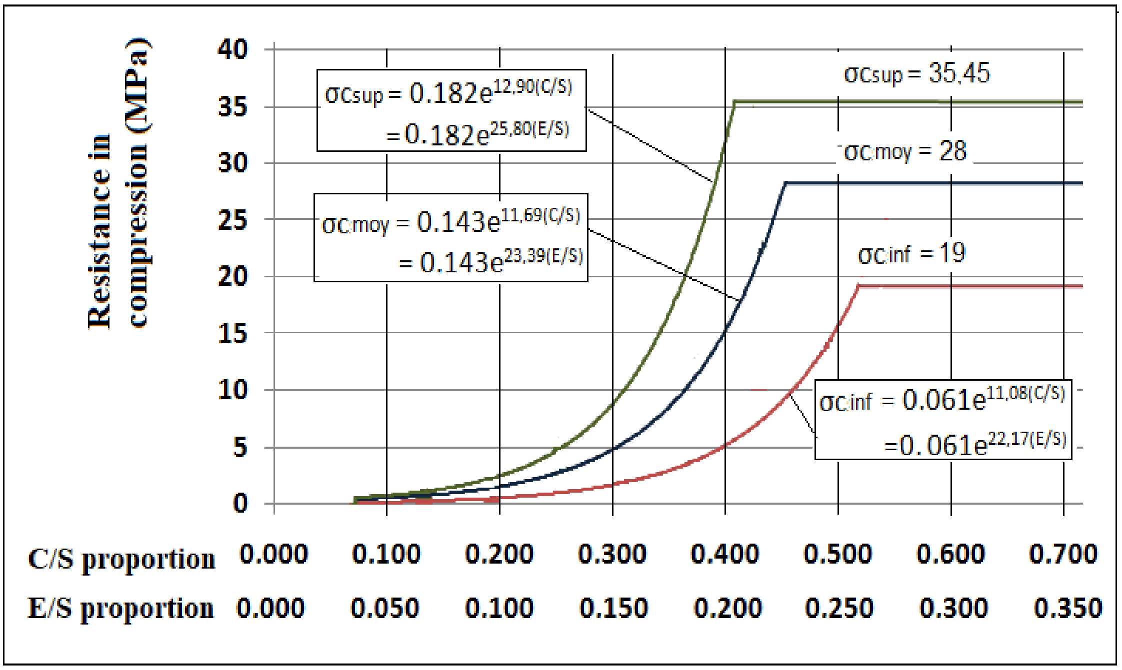

Figure 10. Resistances to optimal compression of silty sands

Figure 10 makes it possible to realize that the proportions E/C = 0.5, C/S>0.53 and E/S>0.3 enable to have optimal resistances of 19 MPa up to 35.45 MPa of mortars made from silty sands of Togo.

4. Discussion

The findings show that, no matter the dosage of the cement, there is a quantity of water (0.5<E/C<0.6) that enables toreach an optimal resistance of mortars. Outside this interval the resistance becomes weak. In fact, for lower quantities of water, hydration of binder (cement) is incomplete; whereas higher quantities of water create bulls in the concrete making it more porous, leading subsequently to the weakening of its resistance. These results on the relation between water on cement (E/C) and resistance are also shown by Dreux G. [10,11,12].

For E/C = 0.5, the evolution of resistances in compression according to the proportion of cement and sand (C/S) and the proportion water and sand (E/S) increases exponentially to a proportion C/S between 0.311 and 0.512 with an average of 0.411 and a proportion E/S between 0.156 and 0.256 with an average of 0.206, and becomes stationary in a logarithmic way beyond these values. The expressions of resistance in compression of mortars, aged 28 days (in MPa) according to proportions C/S and E/S of exponential zones (Figure 10), have the following formula:

$$\sigma_c = ae^{b1(C/S)} = ae^{b2(E/S)} \qquad (5)$$

With *a*, *b* and *c* as constant functions of physical characteristics of sand and properties of cement, and as values:

$$\begin{cases} 0.061 < a < 0.182 \\ 11.08 < b1 < 12.9 \\ 22.17 < b2 < 25.80 \end{cases} \qquad (6)$$

By considering the average values of constants (a=0.143; b1=11.69 and b2=23.39) we reach the equation of the average curve of the resistance (in MPa) given by:

$$\begin{aligned} &\sigma_c = 0.143e^{11.69\left(\frac{C}{S}\right)} \text{ or } \sigma_c = 0.143e^{23.39(E/S)} \\ &for\ \frac{C}{S} < 0.411\ and\ \frac{E}{S} < 0.206 \qquad (7) \\ &\sigma_c = 28 \text{ for } \frac{C}{S} > 0.411\ and\ \frac{E}{S} > 0.206. \end{aligned}$$

The delimitation of the zones of limits through the proportions C/S and E/S enables to distinguish three zones (Figure 11):

- zone 1 corresponds to rich mortars with proportions E/C =0.5, C/S>0.512 and E/S>0.226; these mortars are more appropriate to works the resistance of which is required: the coating mortars on the wall and ceiling for instance:
- zone 2, thin mortars whose proportions are E/C=0.5, C/S<0.311 and E/S<0.156: these mortars can only be used for works whose resistance is not the targeted property: the filling walls for instance;
- A third zone (zone 3) corresponds to mortars whose proportions are E/C=0.5, 0.311<C/S<0.512 and 0.156<E/S<0.226. In this zone, some silty sands of Togo can provide rich mortars whereas others can provide thin mortars.

The dosages in water, cement and sand are provided by the diagram of the Figure 11 which allows to read the dosage in sand according to the types of expected mortars, knowing the quantity of water or cement.

As example, for a dosage in cement of 450kg (C = 450kg) or in water of 225 kg (E = 225kg), that of sand should absolutely be lower or equal to 880 kg (S =3.910x225 = 1.955 x 450 in kg) in order to reach a good resistance whose value is given by equation (7).

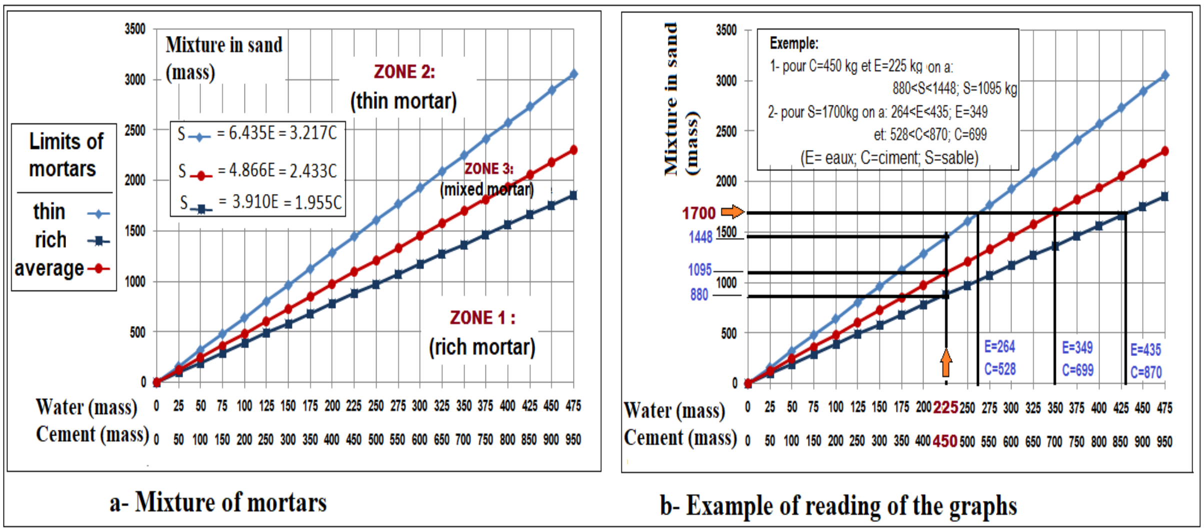

Figure 11. Determination of dosage of silty sand mortars from Togo

5. Conclusion

The purpose of the present study consisted in experimentally determining a formula of mortar on the basis of silty sands of Togo targeting optimal mechanical properties. 1,443 test tubes of mortars gained from silty sand on 12 extraction sites in Togo are prepared with variations of water and cement in the research of the proportion of water and cement (E/C), cement and sand (C/S) and water and sand (E/S). Results show that silty sands of Togo provide mortars:

- rich for proportions E/C=0.5, C/S>0.512 et E/S>0.226;
- thin for proportions E/C=0.5, C/S<0.311 et E/S<0.156;

An expression of the resistance according to the proportion C/S and E/S is also established with graphs and equations that allow deducting the dosages and the resistances of mortars.

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