Algerian Journal of Research and Technology
ISSN : 2543-3954
A.J.R.T Volume 6 (N° 2) (2022) 9 – 23

Treated Soil by Cement to Produce Non-Fired Roof

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Abstract. In demand to minimize the environmental impacts produced by building materials, the opportunity of using cement stabilized soil tiles has been evaluated. Fired clay roofing tiles are one of the most widely used materials in Algerian constructions, whichare produced by firing methods with vast energy consumption and environmental pollution, which can be solved effectively by developing non-firing materials. In this study, non-fired tiles were prepared by mixing soil with different percentages of cement. Laboratory experiments including density, water absorption, porosity, compressive strength, flexural strength and linear shrinkage were conducted on stabilized soil tiles made with three contents of cement (5%, 10% and 15%).The strength values have exceeded the minimum standard requirement for roof tiles (800-1250 kPa) with low water absorption, porosity and lower shrinkage in most samples compared to fired clay tiles.The results obtained made it possible to conclude the possibility of producing non-fired tiles.

Keywords. Soil stabilization, cement, Physical properties, Mechanical, properties, roof tiles

INTRODUCTION

Fired clay tiles are widely used for roof building materials. The energy consumption of tiles and bricks during manufacturing (dry and heating) is about 3200 kJ/kg (Schmittinger et al., 2001), however for keep clay resources and the environment safe, many countries have started to limit the use of tiles and bricks made from clay (Zhao et al., 2012). The fabrication of fired clay tile requires a large number of raw materials, which are used in agriculture areas. Building processes have an unlimited impact on the environment. This deterioration occurs not only by the change of the environment but also by the materials that are used in it (Schmittinger et al., 2001). Materials used for roofing in a building have advanced over time. A sum of them has been developed for specific cause as construction, weather situation, availability, cost, durability, and weight among others (Kolawole et al., 2014). Faced with the environmental problems and the rising cost, it is therefore in urgent to look for alternative materials with low cost and respect environmental rules. To realize this goal, the researcher's team has to prepare compressed treated soil tile by mixing soil with different percentages of cement. Consequently, researchers are committed to developing ecological solutions to reduce both the energy consumption and the pollutant emission of buildings using environment-friendly materials and advanced technological solutions (Sadineni et al., 2011; Cascone et al., 2018). The most commonstabilizers are Portland cement. The quantity and type of addition will be subject to the characteristics of the soil type and the methods of manufacturing compressed stabilized soil tiles or bricks. Consequently, the motivation for these materials is the response of their engineering properties (Sadek, Roslan, 2011; Taallah and Guettala , 2015). Thus, the focus on these materials is the response of their flexural, compressive strength, water absorption, linear shrinkage and porosity. The approach of this study is to required properties in the roof tile through non-firing manufacturing methods. The achieve the specimens to be prepared are to be tested based on standards, to properly characterize it, therefore to confirming that its better choice as roofing tile is properly conducted. A steel mold with interior dimensions of 70 x 140 mm used for unconfined compressive strength, water absorption and porosity.A molddimensions of 40 mm x 40 mm x 160 mm for flexural strength, linear shrinkage. Using an hydraulic machine to control constant load for all specimens during preparation of samples.

MATERIALS AND METHODS

Raw materials for compressed treated soil tiles

The raw materials used involve soils and Portland cement. The natural soil was acquired from the site in Bordj Bou Arreridj, an eastern province. Algeria, which this type of soil not good for agriculture or other purpose. The Portland cement of Matine (Lafarge, 42.5MPa). The basic physical properties of soil are listed in table 1.

Table 1. Basic properties of natural soils.

Properties	
W_L(%)	46.19
Wp (%)	26.54
Ip (%)	19.66
Rc (kPa)	118.5
Ab (%)	>30%
γ_d (Kg/m^3)	1620
Cu (%)	7.13
Cc (%)	2.18

Table 2 present the physical properties and chemical composition of cement.

Table 2. Physical properties-chemical composition of composed Portland cement.

Designation	CEM-II/B 42.5 N NA 442 MATINE	
Physical properties	Normal consistency of the cement paste	25-28.5
	Blaine fineness	4140-5150 μm/m
	Initial setting	140-185 min
	End setting	190-290 min
	Shrink at 28 days	< 1000 μm/m
	Expansion	0.3-2.5 mm
	Compressive strength at 28 days	≥ 42.5 MPa
Chemical composition	Loss on ignition	7 -12%
	Soluble residues	0.7-2%
	Sulfates	2-1.7%
	Magnesium oxide	1-2.2%
	Chlorides	0.01-0.05%
	Tricalcic silicates	57-62%
	Alkalis	0.5-0.75%

Testing procedures

The dry natural soil was sieved through 5 mm and mixed with 5%, 10% and 15% by volume of cement. Then, the optimum water content found from compaction test was added and then using the electric mixer for 7 to 10 minutes to obtain homogenous for all specimens. Subsequently, samples for different moulds sizes were hydraulically compacted using the press at 4 KN. In the end, covered the samples with a plastic bag for 24 h, then transferred immersed samples to the water tank and keep the wet samples in the plastic bag in the humidity room.

The samples were tests concerning: Atterberg limits, compaction test, unconfined compression strength, flexural strength, water absorption, porosity, linear shrinkage, blue methylene and microstructures.

Plasticity index was performed to evaluate the effect of cement dosage on the soil-cement combinations on the physical properties of tile samples. After mixing, the samples were cured in a plastic bag for 24 hours, air dried, crushed, and passed through 425 μm test sieve. The plasticity index was piloted in accordance with British standards methods BS 1377: Part 2 (1990).

Standard Proctor compaction test was conducted to determine the maximum dry density of the soil-cement samples according to BS 1377- part 4 (1990). For mixing purpose, the original soil passed through 5 mm sieve and cement were mixed thoroughly until attained a uniform colour. Compaction was then performed after mixing the combination. Addition of water as needed for the compaction process.

For unconfined compressive strength test, soil specimens were first oven-dried and screened with a diameter less than 5 mm. Three dosages 5%, 10% and 15% of OPC cement were proposed for treated of soil. A volume unite is taken to define cement amount of each dosage. The preparation of samples of unconfined compressive strength tests was mixed soil with different dosage of cement by optimal water content found from proctor test. One layer of compaction was assumed to keep the uniformity of test samples with the mould of diameter is 70 mm and height is 140 mm, a hydraulic press was used to make the sample. After the samples preparation, the first group of samples was covered with plastic and cured for 3, 14 and 28 days (wet condition), second group after 24 h was put in a water tank for 3, 14 and 28 days(immersed condition). The unconfined compressive strength test was done on samples triplicates and average values were used. The test was conducted in accordance with BS 1377: Part 7 (1990).

Same procedures of preparing samples for flexural strength, after preparation the samples compact in the mould of dimensions of 40 mm x 40 mm x 160 mm. The flexural strength, expressed in terms of modulus of rupture, is given in (MPa), and can be calculated as follows ASTM C 78 (2010):

The following equation applies

$$R = \frac{3Pa}{bd^2} \qquad (1)$$

Where,

R = modulus of rupture, MPa

P = maximum applied load, N

a = distance, mm between the line of fracture and the nearest support, measured along the centreline of the bottom surface of the beam

b = average width of the specimen, mm

d = average depth of specimen, mm

Water absorption test was carried out specimens prepared with different dosage of cement and curing time. The specimens immersed in water for 24 h. Then the specimens were cleaned from excess water using tissue paper and then wet mass (W_W) was also weighed, and then the specimens dried in an oven at a temperature of 105 °C for 24 h. Remove each specimen from the oven, and the dry mass (W_d) was also weighed. The test was conducted in accordance with ASTM C 373 (2017). Water absorption was calculated from:

$$W_A = \frac{W_w - W_d}{W_d}\ x\ 100 \qquad (2)$$

The variation of apparent porosity with a dosage of cement and curing time as estimated, the results are compatible with those percent of water absorption, which also compared with dry density and flexural strength.

Linear shrinkage test was performed using a mould dimension of 40 mm x 40 mm x 160 mm. The tests aimed to examine the reduction in linear shrinkage of tile specimens. Usually, for good tiles and bricks, the linear shrinkage must be lower than 8% (Shih et al., 2004). Linear shrinkage rate LS (%) of tile specimens have been calculated by the following equation:

$$LS = \frac{L_i - L_f}{L_i}\ x\ 100 \qquad (3)$$

Mixtures of soil with different dosage of cement sieved through 425 mm. The first group of specimens transferred to the water tank for immersed curing conditions and the second group keep in the plastic bag to maintain moisture content for 28 days for wet conditions. After 28 days which measure the length (L_i) of each specimen and transferred to the drying oven at 105 °C for 24 h. remove each specimen from the oven, and measure the length (L_f). The test was conducted in accordance with BS 1377 (1975).

The methylene blue test makes it possible to determine the cleanliness of soil and to know the type of soil it contains sensitive to water or swelling. The test consists of measuring the absorption capacity of the particles successively elementary doses of a solution of methylene blue and control the absorption of the blue after each addition by performing a task on a filter paper. The test was conducted in accordance with AFNOR NF P 94-068.

The microstructural and elemental maps of untreated and treated soil enable us to proof of pozzolanic reactivity, namely, CSH and CHA. On the basis of SEM and EDX examination, provide the mineralogy formulation, the stabilization mechanism of the treated soil samples and the observation from the tests were described.

RESULTS AND DISCUSSION

Atterberg limit

The plasticity index conducted the soil mixed with cement. As it was expected from the results presented in figure 1, the cement addition to the soil decreased the plasticity index . It can also show that the plasticity index of mixtures decreased as the dosage of added cement increased. The increment in the dosage of cement increased the further reduction in plasticity index of the mixtures. This decrease was marked by a very large variation when the dosage of cement was 5%, a loss was about 91.44%. However the two percentages of 5 % and 10 % of cement are distinguished by a very large gap PI (44 %), and when the dosage of cement between 10% and 15% a small variation can observe. Chemical modification is used to improve soil workability, making the soil easier to use as a construction material. It is used to reduce plasticity and shrink-swell potential (Das, 2010). We can conclude that this value of plasticity index efficiency for tiles compared to some researches (Sultana et al., 2015; Menezes et al., 2005).

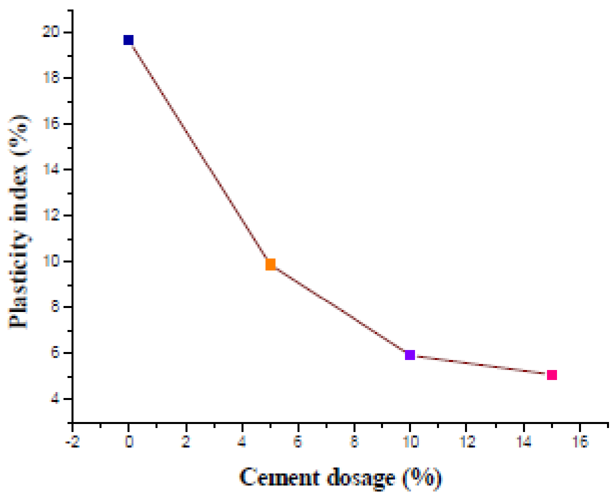


Fig.1. Variation of plasticity index with cement dosage.

Maximum dry density

Figure 2 shows the maximum dry density of soil-cement at a different dosage of cement. As can be seen, the effect of cement on soil characteristics depends on cement dosage. The increase in maximum dry density can be recognized in cooperation with the particle size and specific gravity of the cement and original soil Degirmenci et al., 2006), Nalbantglu, 2004). The values of γd max were proportional to the percentage of cement 1620 kg/m^3 for the natural soil, 1680 kg/m^3 for the 15% cement. This variation can be explained by the fact of adding the cement, the porosity decreases in the soil because of the hydration of the cement which generates a denser soil sample. The increase of the maximum dry density is a demonstration of improvement of soil properties (Harichane et al., 2012; Basha et al., 2005).

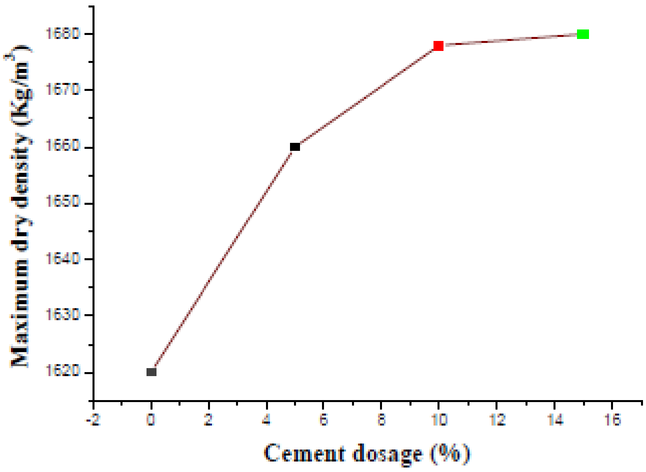
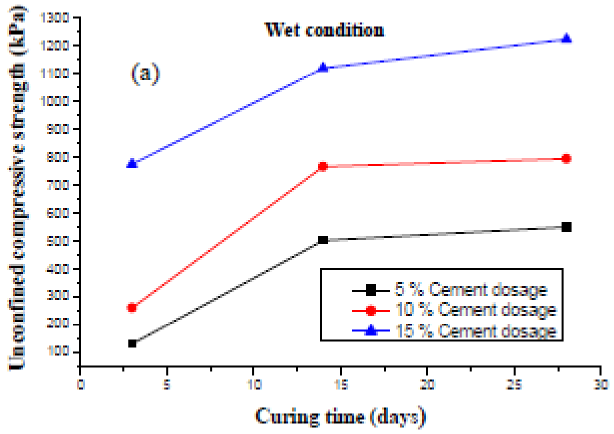


Fig.2. Variation of maximum dry density with cement dosage.

Unconfined Compressive Strength

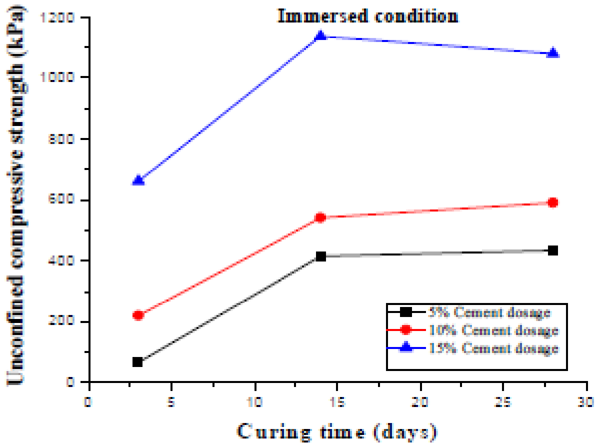
Figure 3 (a), (b) and (c) shows the variation of unconfined compressive strength when increased the cement dosage for different conditions.

The values of the unconfined compressive strength of samples with different cement dosage at 28 days are presented in figure 3. As seen, an increase in cement dosage form 5% to 15% induces a gradual improvement in strength for the samples tested at 28 days. The improvement in strength was about 967.34% for wet condition and 910.63 % for the immersed condition. This increase was marked by a significant variation between 0 % and 15% of cement. However, the cement dosage of 10% and 15% are distinguished by a large difference in strength about 64.89% for wet condition and 54.73% for the immersed condition at 28 days. Also noted was that the compressive strength after 28 days for 15% of cement was greater than another percentage of cement. According to Raheem et al., (2013), the unconfined compressive strength of tiles is around 800 KPa to 1200 KPa, which results in 10% cement suitable to produce the roof tiles.

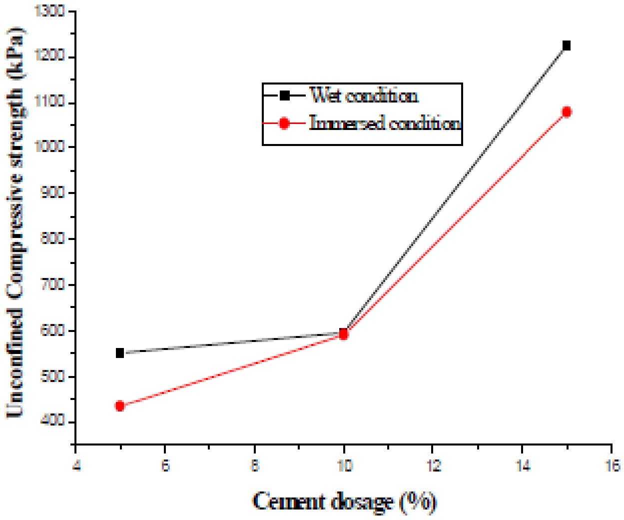


a)

(b)



b)



c)

Fig.3. Variation of unconfined compressive strength with cement dosage.

Water Absorption

It is clear from figure 4 that the water absorption decreased with increased cement content, the cement induces hydration in the soil with water to produce the required cementation products that bond the soil particles to form hard cemented soils. The percentage of water absorbed decreases as the dosage of cement increases, this is due to an increase in the content of cement, which reduces the number of voids existing and show better binding properties. The water absorption ranged from 11.5% to 23%, which lower values when added 15% cement to the soil, which is better value compatible with the specified for tiles (De Silva and Surangi, 2017; Ducman et al., 2010; Sultana et al., 2015). Also, this shows the relationship between the unconfined compressive strength and the water absorption result, since the particles bind, the strength increases and the voids will be reduced.

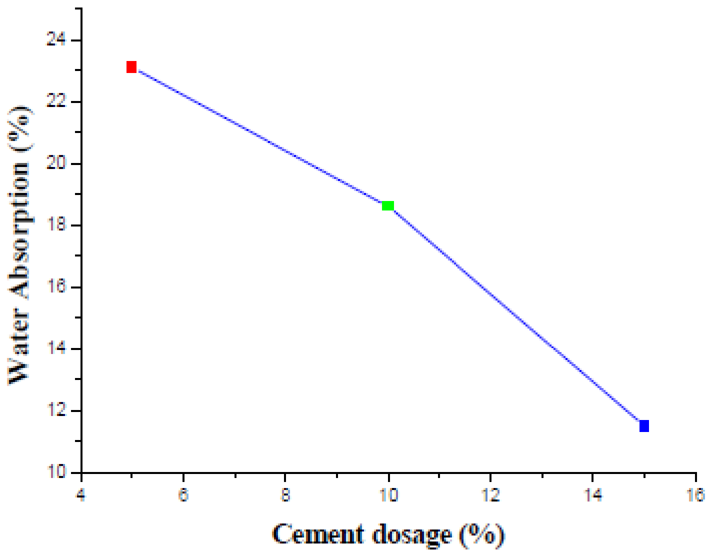


Fig.4. Variation of water absorption with cement dosage.

Porosity

The apparent porosity curves show a similar trend to that of water absorption, with the decrease, values for water absorption and porosity tended to increase the compressive strength and density of the sample occurred.

Figure 5 shows the porosity of treated soil tiles mixture ranging from 11.6% to 14.45% at 28 days. It is evident from this results that the increase in cement content reduced the porosity of mixtures by reducing the voids. The values of porosity similar to the Menezes et al., (2005).

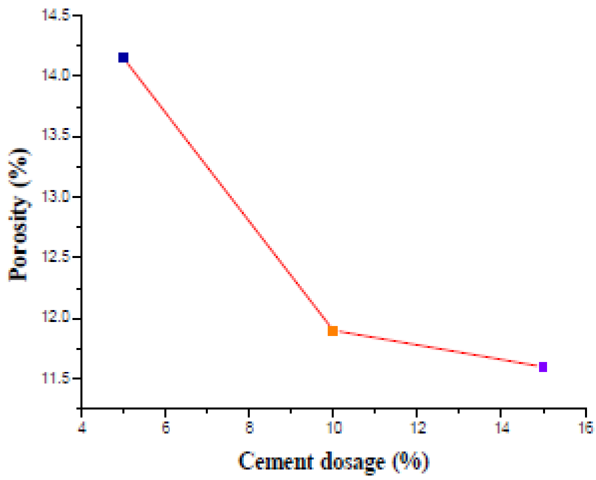


Fig.5. Variation of porosity with cement dosage.

Flexural strength

Figure 6 shows the flexural strength of compressed treated soil tile with a dosage of cement for the wet condition, which observed the flexural strength increased by increasing dosage of cement. When the dosage was 5% the flexural strength was almost the same at 3, 14 and 28 days, but for 10% dosage, we can see big variation at different curing time. Furthermore, not much variation of the flexural strength at 28 days because the hydration of cement needs more time to take action. The peak value of flexural strength was 0.532 MPa with 15 % dosage of cement at 28 days.

Figure 7 shows the flexural strength of compressed treated soil tile with a dosage of cement for the immersed condition, which observed the flexural strength increased by increasing dosage of cement. When the dosage was 5% the lower flexural strength was 3 days, then increased linearly to 0.7 MPa at 28 days. More ever big variation of the flexural strength for 15% dosage at 28 days, high level of cement at 28 days gave the higher flexural strength with the immersed condition.

Figure 8 shows the variation of flexural strength with cement dosage for both conditions (Wet and immersed), it's clear from figure 8 the immersed condition provided a high value of flexural strength. The positive condition of water for cement hydrations, reduce voids of the specimen with time means the materials durable. These results confirmed with Ohijeagbon et al., (2012) and Raheem et al., (2013).

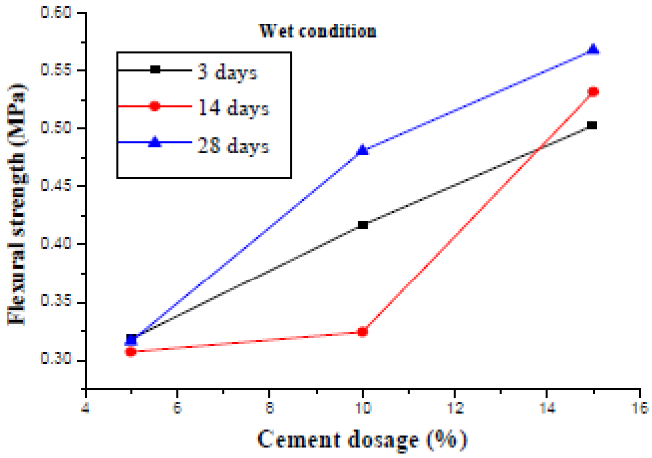


Fig.6. Variation of flexural strength with cement dosage (Wet).

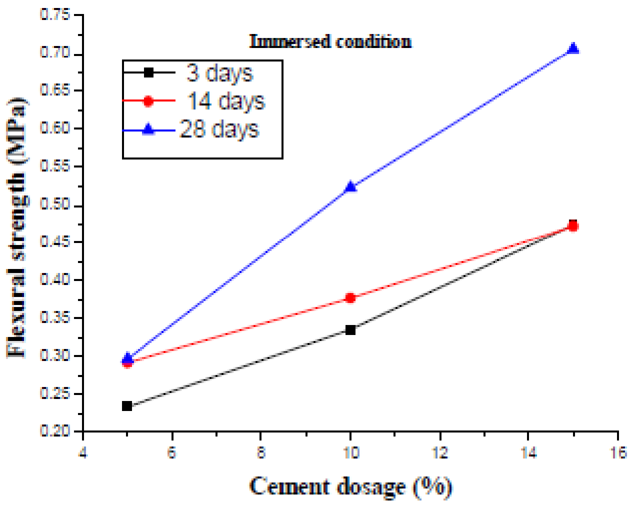


Fig.7. Variation of flexural strength with cement dosage (Immersed).

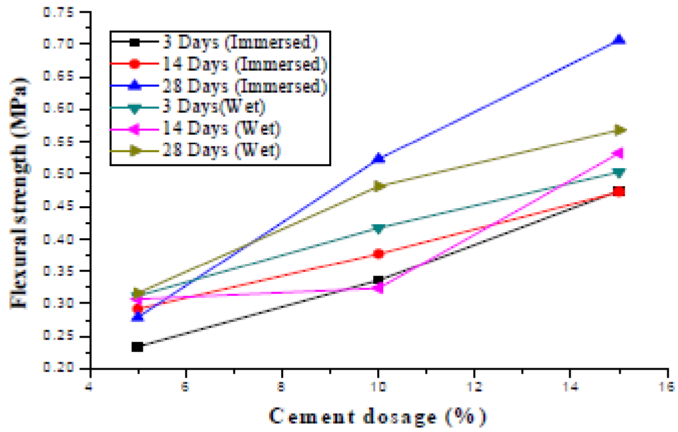


Fig.8. Variation of flexural strength (Wet and Immersed).

Linear Shrinkage

Figure 9 shows the variation of linear shrinkage for the wet condition, which can observe the shrinkage decrease with increasing cement dosage, shrinkage reduced from 8% to 2.2% at 28 days. Thus incomes bond of cement with soil particles. Increasing curing time to 28 days provided minimum linear shrinkage which can obtain the hydration of cement. Additionally, linear shrinkage at 28 days almost constant between 14 and 28 days means the hydration of cement at 14 days nearly completed.

Figure 10 presents the variation of linear shrinkage for the immersed condition, which can also observe the shrinkage decrease with increasing cement dosage and curing time. Increasing curing time to 28 days provided minimum linear shrinkage which can obtain the hydration of cement. Additionally, linear shrinkage at 28 days almost constant between 14 and 28 days means the hydration of cement at 14 days nearly completed.

Figure 11 present the linear shrinkage for both conditions wet and immersed, we can see the lower shrinkage at 28 days wet condition. Additionally, when increasing the cement dosage to 15 % the linear shrinkage keep same values at 14 and 28 days. The lower values of shrinkage for both conditions wet and immersed was between 2.5 and 3%, which is this value stated in Ohijeagbon et al., (2012) and Raheem et al., (2013).

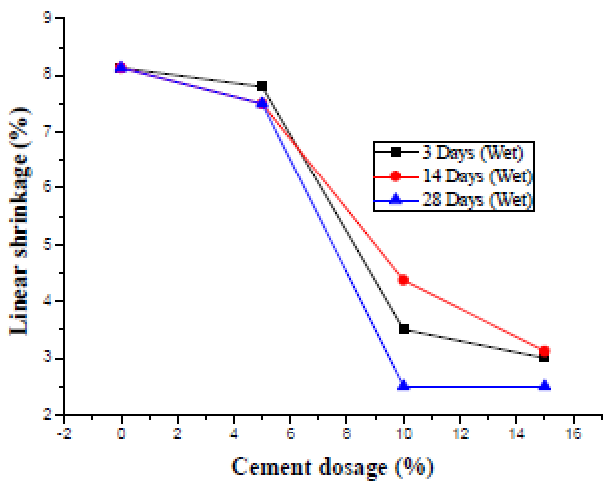


Fig.9. Variation of linear shrinkage with cement dosage (Wet).

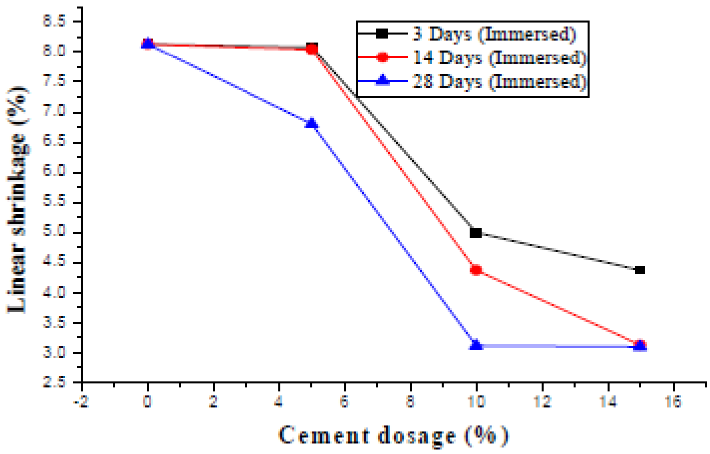


Fig.10. Variation of linear shrinkage with cement dosage(Immersed).

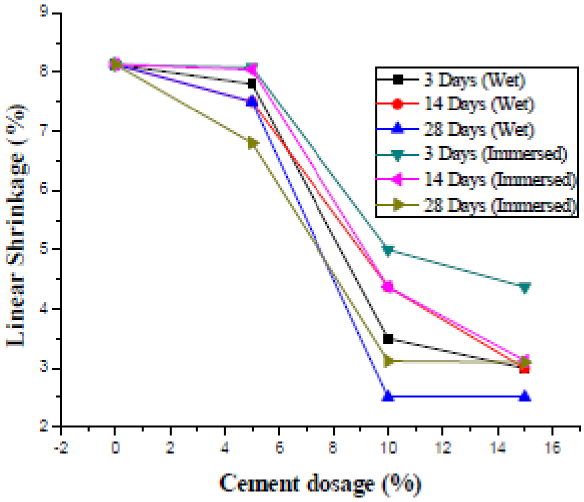


Fig.11. Variation of linear shrinkage with cement dosage (wet and immersed).

Methylene blue

Methylene blue recognizes reactivity of the existed clay fraction existent in a material by evaluating the capability of the fine particles to absorb methylene blue.

Figure 12 shows that the volume of the methylene blue decreases with the increasing of cement dosage. The results show that a very large variation between 0% and 5%, which a decrease in the methylene blue value from 4.33 to 2.67(g/100g). When we increase the cement content from 10 to 15%, we notice a value of blue keep same values, do the bonds of cement with soil particles and reduce clay fraction in new mixtures. As a result, the stabilized soil has lower water sensitivity. This result has been widely studied by Ikhlef et al., (2014).

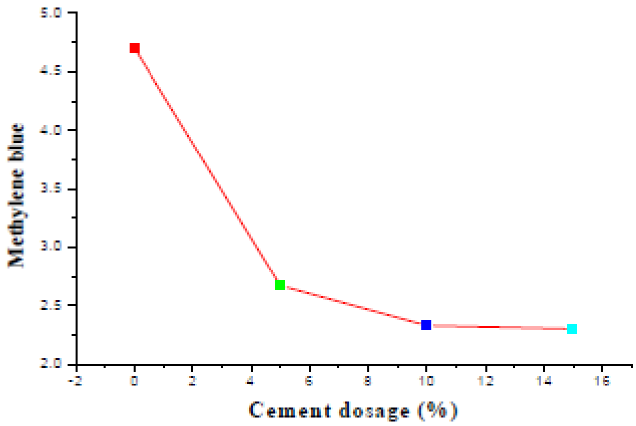


Fig.12. Variation of methylene blue with cement dosage.

Effect cement on microstructures

The electron microscopic examination (SEM) of the samples made on the natural soil, soil-5% cement and soil- 10% cement are shown in figure 13. The SEM results show that large voids and composite wafers in the untreated soil (Fig. 1). The SEM results of the stabilized soil with cement mixtures present small void spaces with the increase in cement dosage. We can also observe fine ettringite crystals.

Such a positive outcome can also be drawn from the finding of Pourakbar et al., (2015). This specified that, although pozzolanic action, a significant proportion of the reaction happens when the maximum relative strength and density achieved. It can be observed from figure 14, which provide the characteristic of natural soil is mainly characterized by high peak of oxide O and calcium Ca with almost same when we added 5% cement to the soil, but when added 10% cement conform the presence of silicium Si, calcium silicate Ca, and oxide O are the three elements of calcium hydrates. It can be also observed that there is a progressive increase in Si with the increase in the dosage of cement. High points of Si, Ca and O were also found in the EDX analysis of stabilized soil from several types of research such as Peethamparan and Olek (2008). This supported alkaline state, which more silica and alumina converted solvable in the natural soil-cement mixture. This allowed the secondary pozzolanic reaction and cementation bonds of mostly secondary calcium silicate hydrates to advanced.

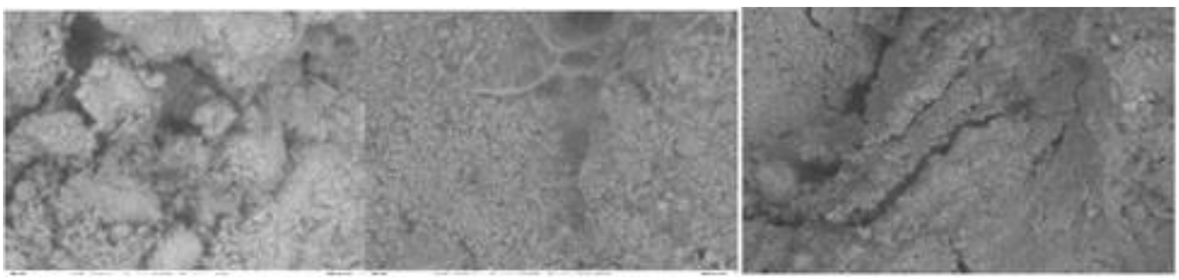


Fig.13. Scanning electron micrographs of the (a) Natural soil, (b) soil-5% cement and (c) soil- 10% cement.

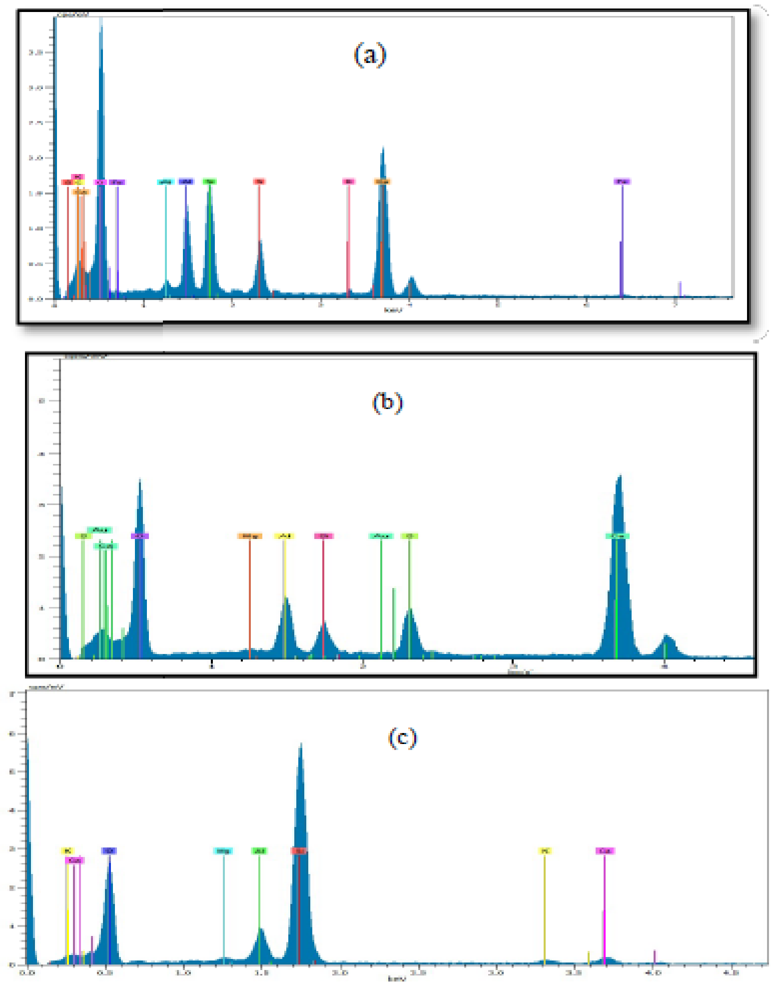


Fig.14. Energy descriptive X-ray for (a) natural soil, (b) soil-5% cement and (c) soil-10% cement.

CONCLUSION

Based on the laboratory tests, the effects of cement on the treated soil to product non-fire roof tiles have been examined. It is exposed from the laboratory test results that the addition amount of cement causes the positive changes in the Atterberg limits, compaction, unconfined compressive strength, water absorption, flexural strength porosity, linear shrinkage and blue methylene used in this study. It is observed form laboratory testing that the properties of soil vary on depend on cement dosage and curing time. The increase of cement dosage and curing time decrease the plasticity index of about 91%. However, increasing the dosage of cement and curing time increase the strength to about 910% and reduce water absorption by about 54 %. Through this investigation, it is obviously noted that the cement as a soil stabilizer is practical to produce roof tiles by improving the strength, minimize the water absorption and porosity, which save energy consumption, reducing the cost and limit the gaze's emission to the atmosphere.

ACKNOWLEDGMENTS

The authors genuinely thanks the University Centre of Ain Temouchent, University of Bordj Bou Arreridj and the ministry of higher education and research scientist for financial support during the study (Fund N°: J0406320140008).

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