Cement & Concrete Composites 26 (2004) 811–820

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Performance of compacted cement-stabilised soil

R. Bahar [a], M. Benazzoug [a], S. Kenai [b,*]

[a] Geomaterials and Environment Laboratory, University of Tizi-Ouzou, P.O. Box RP 17, Tizi-Ouzou 15000, Algeria
[b] Geomaterials Laboratory, Civil Engineering Department, University of Blida, P.O. Box 270, Blida 09000, Algeria

Received 6 November 2002; accepted 12 January 2004

Abstract

Earth construction is widespread in desert and rural areas because of its abundance and cheap labour and could be an alternative construction material for low cost housing in Algeria. However, earth construction suffers from shrinkage cracking, low strength and lack of durability. This paper reports on the Algerian experience on earth construction in housing and gives an extended review of an experimental study to investigate a stabilised soil by either mechanical means such as compaction and vibration and/or chemical stabilisation by cement. Soil used was characterised by its grading curve and chemical composition. Compaction was either applied statically or dynamically by a drop weight method. A mixture of sand and cement was also tried. The effect of each method of stabilisation on shrinkage, compressive strength, splitting tensile strength and water resistance are briefly reported. The experimental results showed that the best method of stabilisation of the soil investigated, which gives a good compressive strength and a better durability at a reasonable cost, could be a combination of a mechanical compaction and chemical stabilisation by cement or sand and cement up to a certain level.

Keywords: Low-cost construction; Earth blocks; Compaction; Cement; Sand; Shrinkage; Compressive strength; Flexural strength; Durability; Water resistance

1. Introduction

Soil based construction blocks have been used in North Africa for centuries, especially in rural regions and in the desert. Soil could be stabilised either by manual compaction, mechanical compaction or natural fibres. Some historical cities such as Temimoun in the Algerian Sahara are known of their mud coloured houses and are a continuous source of inspiration for modern architects. However, with the development of masonry and reinforced concrete, soil based constructions are regarded as designed for the poor people and hence of lower quality. This is mainly due to their durability problems such as the lack of water resistance and erosion.

Conventional materials such as cement, aggregates, steel and bricks are lacking, imported and quite expensive. Hence, the need to find alternative local low cost construction materials which do not require special skills and special machines and equipment for their fabrication and where traditional experience by local people is available.

In 1984, following an instruction from the Algerian ministry of housing to local authorities to encourage the use of local construction materials in rural and desert regions, a lot of research work was encouraged in universities and research centres for the development of local low cost construction materials such as gypsum, lime, sand dune and stabilised soil [1–4]. Prototypes and housing projects in different regions of Algeria as well as in the desert were built. Much of the work was on stabilised soil blocks as it is available everywhere and previous historic experience exists [5,6]. Some hydraulic machines were developed to ease compaction and to get blocks similar to concrete blocks. Chemical stabilisation by cement, lime and by natural fibres were investigated. However, soils differ from one region to another and a comprehensive study of their performance is needed. Little work was done on durability tests such as water permeability and water absorption. The influence of different compaction methods on the mechanical properties and water resistance requires further study.

* Corresponding author. Tel./fax: +213-25433939.
E-mail address: sdkenai@yahoo.com (S. Kenai).

0958-9465/$ - see front matter
doi:10.1016/j.cemconcomp.2004.01.003

This paper summarises an experimental investigation on the effect of compaction and chemical stabilisation by ordinary Portland cement on the performance of earth blocks. Particular attention was given to the improvement of its compressive strength and its resistance to water. The effect of method of compaction on mechanical properties and water resistance was also investigated.

2. Earth construction in Algeria

Earth construction has been the most widely used building materiel throughout the long history of Algeria. Some historical cities in the desert and mountainous regions are known of their experience in the use of this low cost material in housing projects (Fig. 1). However, the main drawback of this material is the need for continuous maintenance and the lack of durability and resistance to water. Many failures have been reported after seasonal flooding in some cities in Algeria, which undermined the use of earth blocks and led local people to the use of concrete blocks and burned bricks. However, due to its higher cost and lower thermal performance, much interest is going back to earth construction, which is known for its cheap labour and low cost and comparable thermal insulation characteristics. Different types of earth construction are used in North African countries and are briefly reviewed.

2.1. Rammed earth or pisé

It is one of the oldest technique and consists of pouring earth stabilised by natural fibres or a binder in pre-prepared formwork for wall construction with manual compaction in segments around 1 m high. This technique is suitable for soils with high percentage of large grain size particles. Some recent housing projects, experimental buildings and prototypes using this method are reported in Algiers as well as in the desert villages and towns [1,5]. An interesting experience has been reported in North Africa using a similar technique for building low cost grain silos in rural regions using earth stabilised by wheat straws [7].

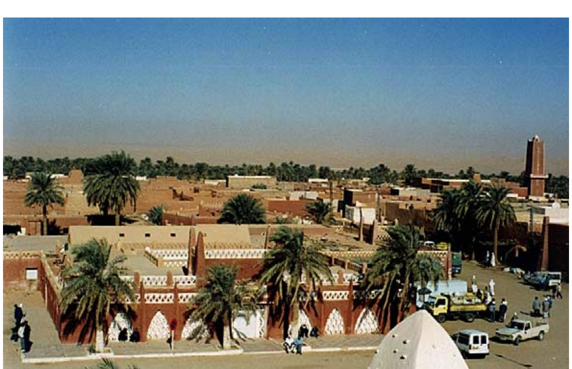

Fig. 1. A general view of earth construction in the city of Temimoun in the south of Algeria.

2.2. Adobe construction

Adobe blocks are prepared manually in wooden moulds and dried in the open air. Straw is sometimes used to reduce cracking. This technique is mostly used in rural areas in self-built housing projects. However, the quality of the blocks is usually unsatisfactory due to surface cracking and the buildings need continuous maintenance to be durable and water resistant. Mechanical compaction is sometimes applied with metallic moulds to enhance the performance of the blocks.

2.3. Soil stabilised blocks

This technique is commonly known as the cement-stabilised soil and most research work has been done in this area. A clay sandy soil is usually used after being mixed with some cement or lime in the forms, hydraulically compacted and then cured. Hence, higher compressive and tensile strengths, better cohesion and better water resistance are obtained thus improving its natural stability. Reinforcement with barley straw was also tried and gave a better performance with regard to compressive and flexural strengths as well as shrinkage [8]. Although some recommendations [9,10] for their fabrication, testing, construction and quality control were issued by the ministry of housing in collaboration with the centre for research on earth construction CRATerre of Grenoble in France, further research work is still needed to improve stabilised soil performance. Mechanical properties and durability improvement is sought in different laboratories in the world using better mixes, admixtures and different fibre reinforcement [11–17].

3. Materials used and test methods

3.1. Materials used

Typical clay sandy soil from the region of Tizi-Ouzou, east of Algiers, that is a very populated mountainous region known for its earth construction and local traditional pottery industry was used. Soil was first passed through a 5 mm sieve before being characterised for its grading curve, consistency limits and chemical composition. The sand used was fine river sand passing a 0.63 mm sieve. Ordinary Portland cement type CEMI 32.5 was used for the chemical stabilisation.

3.2. Testing methods and testing program

Preliminary tests such as compressive strength in the dry state and after 48 h immersion in water were first conducted on the soil blocks without stabilisation. Chemical stabilisation was investigated by adding 0%, 4%, 6%, 8%, 10%, 12%, 15% or 20% of cement by weight of soil and its effect on compressive and splitting strength at different curing times was analysed.

Samples for testing are prepared by first drying the soil in an oven, and a homogeneous mixture obtained by blending the required amount of cement with the dry soil in a mechanical mixer before adding water and further mixing. The mixture is put in a normalised Proctor mould, covered with a sheet of plastic for 24 h before being demoulded and then left in the air laboratory until the age of testing. Tests were conducted according to the local [9,10] and to the RILEM TC 153 recommendations [18]. Compressive strength was determined on samples prepared in compaction moulds under standard Proctor conditions. Splitting tensile strength was determined using 100 mm diameter and 100 mm height cylindrical specimens compacted as Proctor and tested at a loading rate of 0.05–0.1 N/mm^2/s after being dried in an oven at 105 °C for 24 h. The initial tangent modulus of elasticity was calculated from the slope of the stress–strain curves of 100 mm cylindrical samples under compression.

The effect of stabilisation by a mixture of cement and sand on shrinkage, conductivity and water permeability was also investigated. Linear shrinkage was measured on 100 mm cylindrical samples compacted as Proctor and stabilised with cement, sand or a mixture of cement and sand. Specimens were dried inside the laboratory at about 25 °C and 65% R.H. and the linear shrinkage (change in length) measured using a dial gauge. The coefficient of permeability was measured using a falling head permeability apparatus and cylindrical specimens of 50 mm diameter and 100 mm height [19]. Cylindrical specimens were used for the conductivity tests using the experimental set-up shown in Fig. 2. An electrical current is passed through the specimen and the electrical intensity and the potential difference are measured between two points and hence conductivity calculated.

The effect of a combined chemical stabilisation by cement and mechanical stabilisation by static, vibro-static and dynamic compaction on the mechanical properties was studied. A modified Proctor test designed in the laboratory was used in order to overcome the drawbacks of static compaction which cannot lead to a perfect grain arrangement whatever the static pressure applied. The mould is filled in one layer by the mix and the dynamic compaction is obtained by dropping a 12.5 kg falling-weight from a height of 820 mm on cylindrical specimen 120 mm in diameter and 180 mm in height and the number of drops is increased until the desired compaction energy per unit volume of the soil is obtained (Fig. 3). Four levels of compaction energy by unit volume of soil (E_v) were fixed 3.0, 5.5, 8.3 and 10.3 J/cm^3.

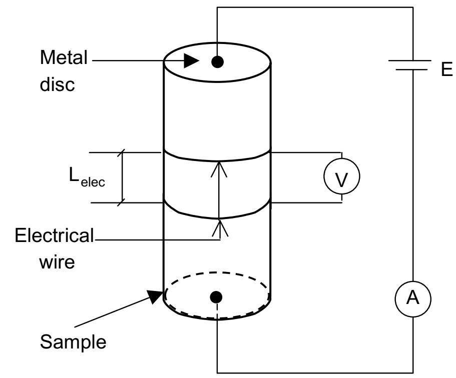

Fig. 2. Set-up of the conductivity test.

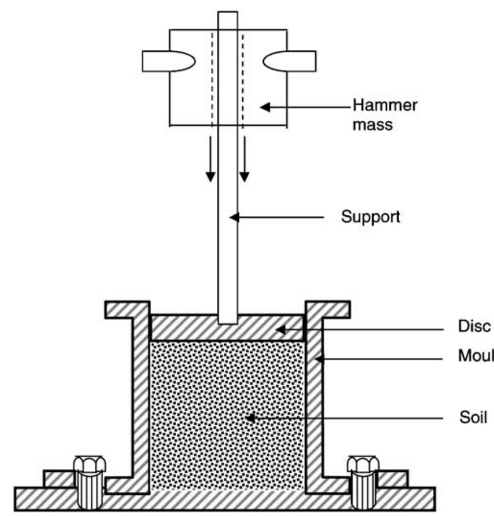

Fig. 3. Experimental set-up of the dynamic compaction.

Static compaction is obtained by applying a static pressure using a universal compression testing machine on stabilised soil placed in a cylindrical mould 100 mm in diameter and 165 mm in height and compacted at a strain rate of 1.27 mm/mn until the desired compaction stress is obtained. After demoulding, the height and the density of the specimen are measured and the specimens are left in to air cure in the laboratory until testing at the age of 28 days.

In order to enhance the performance of stabilised soil, specimens were first vibrated on a laboratory-shaking table for one minute before being subjected to a static compaction force. For the optimum water content, slightly higher dry and humid compressive strengths were obtained as compared to static compaction.

Durability tests by water absorption, by water capillary and by accelerated erosion tests were also investigated. The experimental set-up for the water absorption capillary is shown in Fig. 4. The coefficient of water

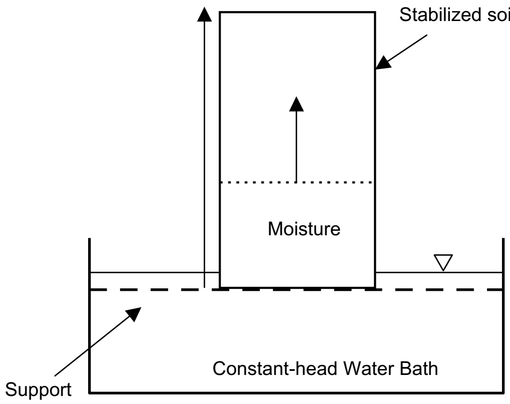

Fig. 4. Schematic set-up of the water absorption by capillary test.

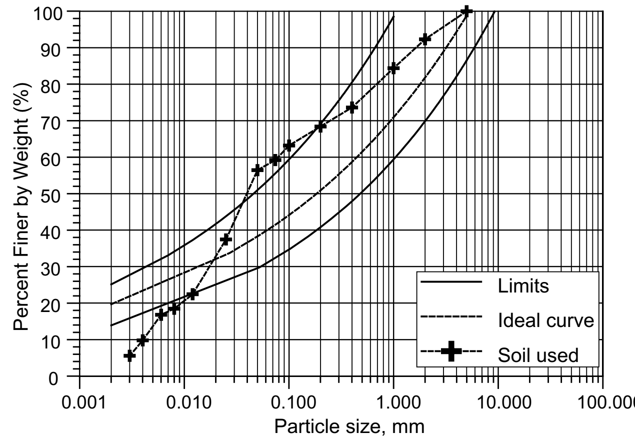

Fig. 5. Grain size distribution.

absorption by capillarity (sorptivity) (C) is measured by immersing the lower side of the specimen of an area (A) at a 5 mm constant head-water bath and then measure the quantity of water absorbed (M) after $t = 10$ min on specimens cured for 7 days (cycle 1) and the test repeated on the same specimen at the age of 14 days (cycle 2):

$$C = M/At^{1/2} \quad (1)$$

Accelerated erosion tests were performed by subjecting the specimens to "water showers" for 2 h from a distance of 0.18 m at a water pressure of about 100 kN/m^2. The weight loss is measured and the effect on the surface of the specimens noted at the end of the test.

4. Experimental results

4.1. Chemical stabilisation of the soil by cement addition

Table 1 summarises the characteristics of the soil used. Fig. 5 gives the grading curve of the soil used as compared to the standard upper and lower limits for a stabilised soil. The limits are recommended to get a well-graded soil easy to compact and containing lower fines content so that it will be less sensitive to water. It can be seen that the grading curve of the soil used is within the limits for a well-graded soil but with a small excess of 0.1 mm particles and lack of fine particles. However, no grading correction was applied. The soil has a liquid limit of 39%, and a plasticity index of 15% and hence could be classified as moderately plastic clay type A6 according to the American Association of State Highway Transportation Officials (AASHTO) system. The chemical composition showed that harmful substances such as sulphate, chloride and organic matters are negligible and that this clay is rich in carbonate.

Compressive and tensile strengths were determined using a sample of five for each level of cement stabilisation. The modulus of elasticity was calculated on samples with either 0% or 10% of cement by weight.

Table 1
Identification and characteristics of the soil used

Property		
Atterberg limits	Liquid limit w_L	39
	Plasticity index I_p	15
Grain size distribution	Gravel (>4.75 mm) (%)	7.7
	Sand (0.074–4.75 mm (%)	30.3
	Clay and silt (<0.074 mm) (%)	62.0
Chemical characteristics	Iron oxide–alumina (%) (Fe_2O_3–Al_2O_3)	15.8
	Carbonate $CaCO_3$ (%)	34.0
	Chloride NaCl (%)	0.17
	Sulphates $CaSO_4$ (%)	0.0
	Insoluble residue I.R. (%)	45.5
Normalized Proctor test	Optimum water content (%)	11
	Maximum dry density (kN/m^3)	17.6
Sand equivalent	By piston test (%)	15.60
	By sight (%)	28.57

4.1.1. Strength and elasticity

The optimum water content for the soil without stabilisation was obtained using a normalised Proctor mould and was 11% by weight of soil for a maximum dry specific density of 17.6 kN/m^3. Compressive strength at the dry state and compressive strength after immersion in water for 48 h at the age of 28 days are given in Fig. 6. It can be seen that the increase of the cement content increases the compressive strength because the hydration products of the cement fill in the pores of the matrix and enhance the rigidity of its structure by forming a large number of rigid bonds connecting sand particles.

Splitting tensile strength at the dry state is given in Fig. 7, where it is shown to increase with the increase in cement content up to about 10% of cement content and beyond that the increase in tensile strength is slow. Splitting tensile strength tests of immersed specimens were performed but are not reported as they were very low.

The immersion in water for 48 h reduces the compressive strength by up to 60% for cement-stabilised samples and complete disintegration of un-stabilised specimens was observed in few minutes. The reduction in strength was lower with higher cement content up to an optimum level of 10%, which gives the lowest reduction in strength of about 50%. Higher increase in cement content does not give any positive effect in the wet samples.

The effect of the age of curing on the compressive strength is shown on Fig. 8. It can be clearly seen that the relative compressive strength obtained after 7 days of curing was about 70% of that obtained after 21 or 28 days of curing for up to 10% of cement content. However, the relative compressive strength at 21 and 28 days for 12%, 15% and 20% of cement content as compared to that at 7 days was only about 50%. This shows that higher cement content than 10% need a period of curing of 21–28 days for the complete strength to be developed.

The modulus of elasticity was calculated for stabilised soil with only 0% and 10% of cement content using the stress–strain curves (Fig. 9). It can be seen that the cement stabilisation increases the slope of the curve and hence the elastic modulus of the material increases from 1.89 GPa for un-stabilised soil to 2.51 GPa for 10% cement-stabilised soil. It should be noted that the results reported here on compressive and tensile strength and initial tangent modulus are much higher than those reported on soil stabilised with lime and fly ash [20,21].

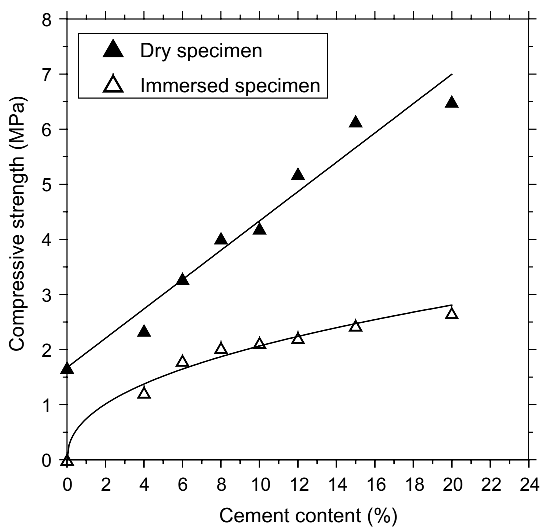

Fig. 6. Compressive strength for dry and immersed specimen.

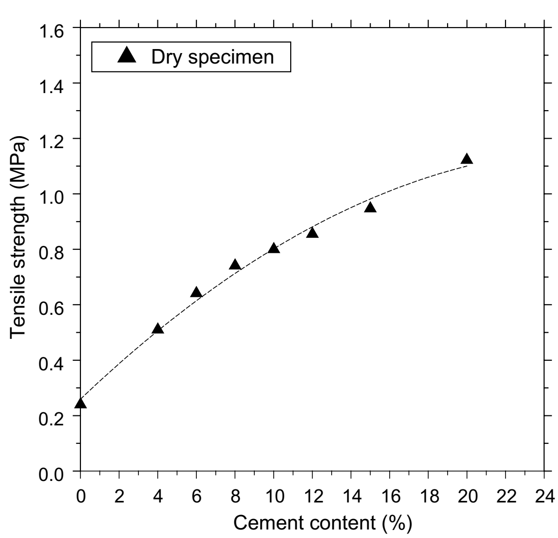

Fig. 7. Splitting tensile strength.

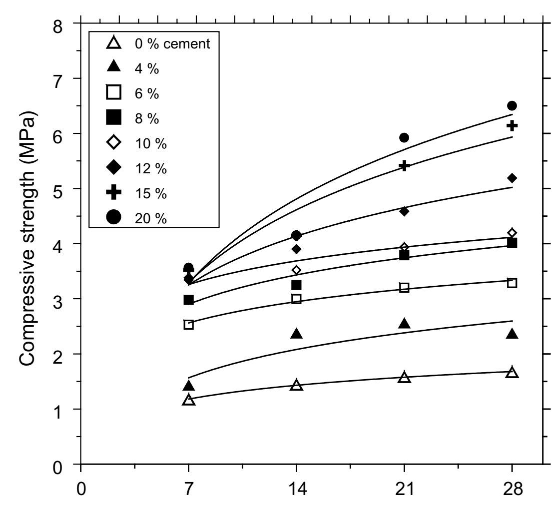

Fig. 8. Effect of age of curing on compressive strength at different cement contents.

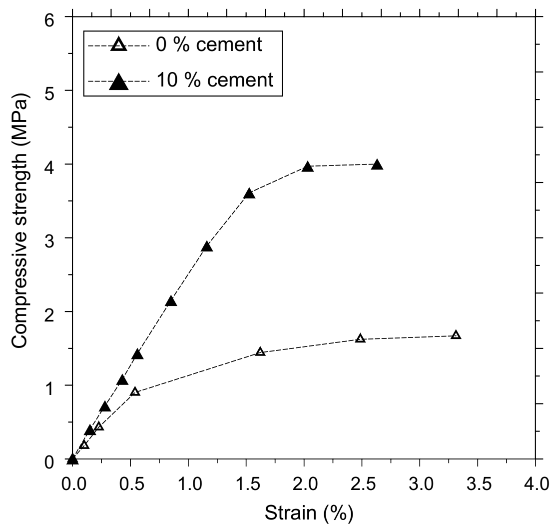

Fig. 9. Stress–strain curve for sample under compression.

4.1.2. Shrinkage

Fig. 10 shows typical variation of shrinkage with time for cement-stabilised soil. Shrinkage increases rapidly during the first 4 days for both cement-stabilised soil and un-stabilised soil specimen and then at a later ages the increase is very slow. Hence, curing for the first 4 days could be beneficial in reducing drying shrinkage and cracking. The shrinkage of cement-stabilised soil at 25 days of age as compared to that of un-stabilised soil was reduced by about 20% and 44% for 6% and 10% of cement content respectively.

Table 2 summarises the results of the final shrinkage at 25 days of age for specimens with a combination of sand and cement. As expected, the higher the water content, the higher is the shrinkage for un-stabilised soil specimens. The addition of sand reduces the shrinkage as sand particles oppose the shrinkage movement. The reduction in shrinkage was about 29% and 64% for 10% and 15% of sand content respectively. Further increase of sand content did not affect the shrinkage. The combination of cement and sand reduces the shrinkage slightly better than when only cement is added. A mixture of 5% sand and 15% of cement seems to give the lowest shrinkage when a combination of cement and sand was added.

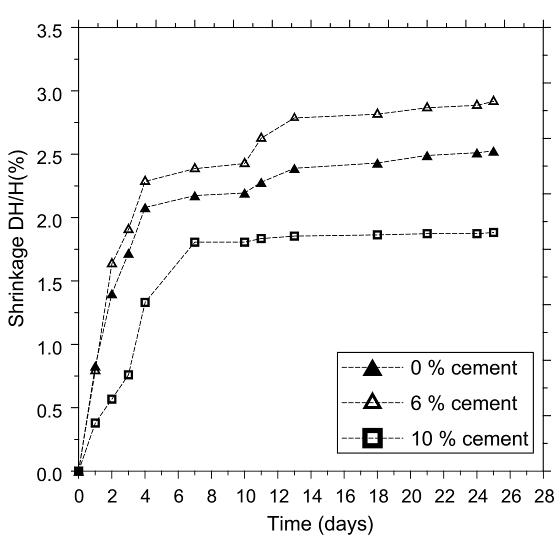

Fig. 10. Effect of cement content on the development of shrinkage.

4.1.3. Water permeability

The effect of cement content on the water permeability coefficient is shown in Fig. 11. As expected the addition of cement reduces water permeability. The water permeability coefficient decreases from 14×10^{-8} to 0.27×10^{-8} m/s when cement content increases from 5% to 20%. This shows that stabilisation of the soil with cement could lead to a better mechanical strength and lower permeability and hence better durability.

4.1.4. Conductivity

The electrical conductivity was measured in order to get a qualitative assessment of the thermal conductivity of the material. Fig. 12 shows that conductivity decreases slightly with the increase of cement content and sand content. The higher conductivity for low cement contents could be attributed to the low consumption of mixing water by hydration for low cement contents and hence to the higher quantity of available conductible free water.

4.2. Mechanical stabilisation of the soil by compaction

The main objective of soil compaction is to increase the soil density, decrease the voids ratio, reduce the soil porosity, water permeability and water resistance and hence enhance its durability. The densification of the soil mass also makes particle reorientation and formation of cracks more difficult. Three different methods of compaction: dynamic, static and vibro-static were studied and their effect with the percentage of cement on the soil characteristics and performance investigated.

4.2.1. Dynamic compaction

The variation of the dry density with water content and compaction energy is shown in Fig. 13. The optimal water content is about 9.5–11.0% and the maximum dry density about 20.0 kN/m^3 for all energy compaction levels. The increase of the energy compaction increases the dry compressive strength by more than 50% but reduces the optimum water content from 12% to about 10% (Fig. 14). The increase in compressive strength and dry density with increase in compaction energy was more pronounced when specimens were moulded on the dry side than on the wet side of the optimum moisture content. After immersion in water, higher dynamic

Table 2
Variation of final shrinkage with water, sand and cement contents

Water content (%)	8.63	10.0	12.0	13.43	16.56	19.28
Final shrinkage (mm)	0	0	0.86	2.59	3.8	6.03
Sand content (%)	5	10	15	20		
Final shrinkage (mm)	1.74	1.73	0.88	0.87		
Cement (C) + sand (S)	5%C + 15%S	10%C + 10%S	15%C + 5%S			
Final shrinkage (mm)	1.12	1.11	0.74			

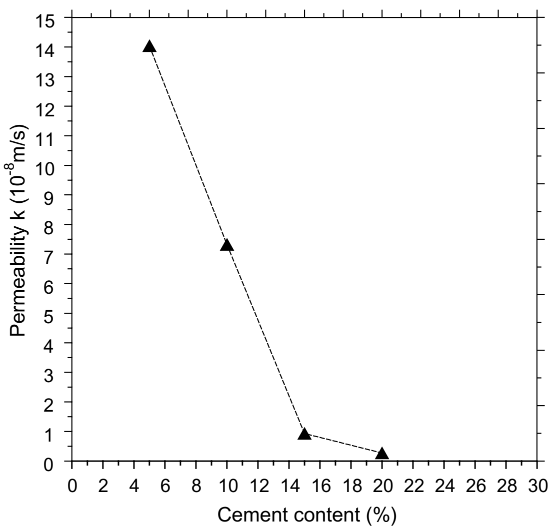

Fig. 11. Effect of cement content on the water permeability.

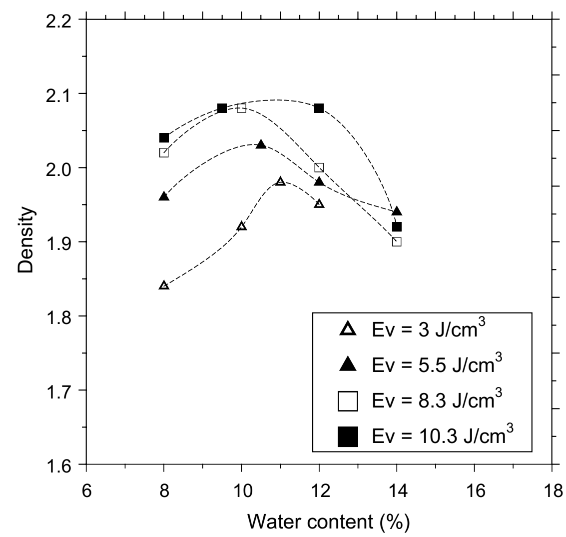

Fig. 13. Variation of dry density with water content under dynamic compaction.

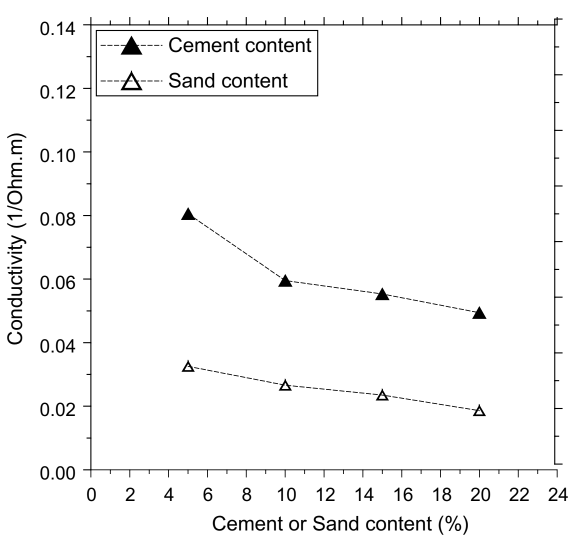

Fig. 12. Effect of cement and sand content on the conductivity.

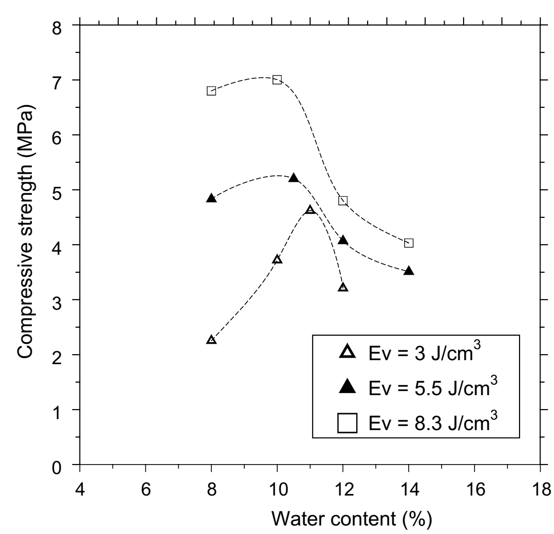

Fig. 14. Variation of the compressive strength with water content under dynamic compaction.

compaction energy gave a residual compressive strength of about 2 MPa as compared to a complete disintegration for un-stabilised non-compacted specimen.

The effect of cement content was studied for compaction energy of 8.3 J/cm^3. Preliminary tests showed that the optimal water content for stabilised soil specimens was about 12%, as extra water is needed for cement hydration and hence it was fixed at that level for all tests. The compressive strength was almost doubled when cement content increases from 2% to 12%. However, the compressive strength after immersion in 48 h was only about 20–25% of the dry compressive strength for all cement content levels. This is a low value for a combination of chemical and mechanical stabilisation and may be due to the nature of the soil used itself and to the severity of the test of 48 h complete immersion in water which could be rarely encountered in practice for a well designed building. However, the residual compressive strength for cement content higher than 6% was higher than the 2 MPa required usually for concrete blocks.

4.2.2. Static compaction

As expected, the dry density increases with the applied compressive stress. The optimal water content was about 10–13%. The dry compressive strength also increases with the static applied stress and cement content (Fig. 15). About 60% increase of the dry compressive strength was obtained when the applied static stress increased from 2.1 to 7.3 MPa.

4.2.3. Vibro-static compaction

Vibro-static compaction increase slightly the compressive strength. The average increase in strength was about 5% (Fig. 16). Vibro-compaction does not seem to enhance the performance of the soil when lower water content is used and in this case static or dynamic compaction are better. However, for higher water content than the optimal values vibro-compaction seems to be the best compaction method probably because of the low friction forces.

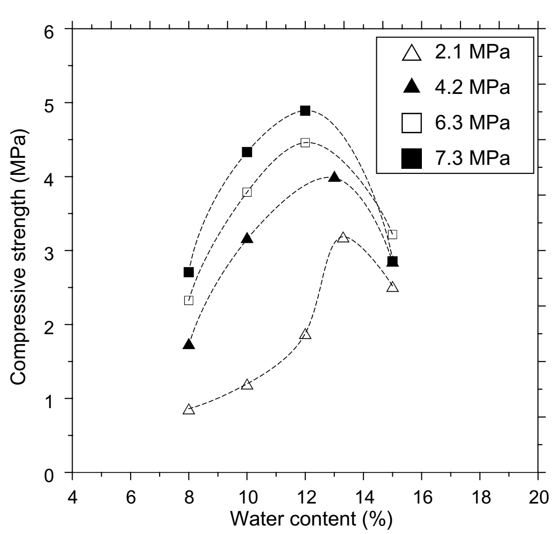

Fig. 15. Compressive strength under static compaction.

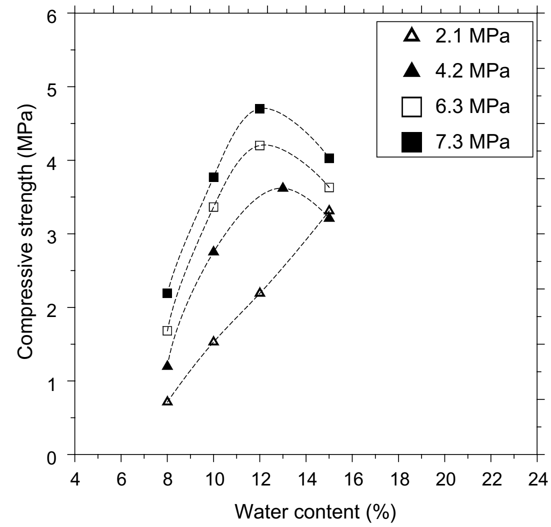

Fig. 16. Compressive strength under vibro-static compaction.

4.2.4. Comparison of different compaction methods

The three different methods of compaction used in this investigation do not affect significantly the dry density of the soil. Fig. 17 gives the compressive strength under different compaction methods and with different cement content in the dry state and after water immersion. It can be seen that, for dry specimens, dynamic compaction offers the highest compressive strength at all level of cement stabilisation. Higher dynamic compaction gave a compressive strength in excess of 10 MPa as compared to a maximum of 8 MPa for static compaction. At 12% of water content, the increase of cement content from 2% to 15% increases the compressive strength from 4.25 to 8.2 MPa, for static compaction and from 5.9 to 10.5 MPa for dynamic compaction.

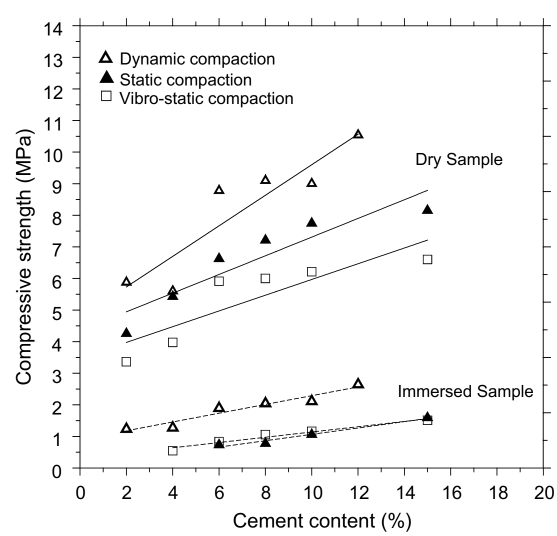

Fig. 17. Effect of compaction method on compressive strength of dry and immersed samples.

It seems that the vibration does not enhance the strength probably because of the low frequency of the laboratory-vibrating table, which is not adequate for a fine material. Dynamic and static compaction with 2–4% cement content give a similar dry compressive strength as that of vibro-compaction at 6% of cement content.

Although the static compaction yielded higher dry compressive strength than the vibro-static method, the static compaction was slightly less efficient for the compressive strength after water immersion for 48 h where only 10–19% of the dry compressive strength was obtained for cement content higher than 6%. The compressive strength after immersion in water for 2% and 4% cement content was negligible for all compaction methods and hence the importance of having a higher cement content. It seems that for water resistance, dynamic compaction is the only recommended method of compaction, as it was the only method, which gave higher strength than 2 MPa for more than 6% of cement content. In practice, for large scale block production, dynamic machines which compress the blocks by a vertical stroke piston or could vibrate the soil during compression to produce superior quality products are reported [14,22,23]. However, it is costly, time consuming and difficult to achieve. The superior performance of dynamic compaction blocks showed that the soil used could also be suitable for rammed earth production.

4.3. Water resistance

Water resistance was studied by measuring water absorption after immersion or by measuring the height of water penetration by capillary.

4.3.1. Water absorption by immersion

Water absorption is measured by the increase in weight for a specimen stored for 21 days in an environment at 20 °C and 50% R.H. and then immersed in water for 24 h at a height of 5 mm before being totally immersed in water for 3 days. The specimens used are prepared with 12% water content in a normal Proctor mould. The increase in weight is summarised in Table 3. The increase seems to be quite high (13–17%) though the increase for cement content higher than 10% was negligible.

4.3.2. Water absorption by capillary

Higher coefficient of water absorption is observed during the second cycle of the testing at 14 days than that of the first cycle (Table 4). Hence continuous cycling water contact of stabilised blocks from for example rain or underground or roofs could lead to a very high water uptake and probable failure. During the first cycle, lower water absorption is observed for cement content higher than 10%. The combination of dynamic compaction ($E_v = 8.3$ J/cm^3) and chemical stabilisation reduces substantially the sorptivity from 11.9% for 0% cement content to 9.8% and 2.7% when cement content is 5% and 10% respectively (Table 5). This is lower than the water absorption with only chemical stabilisation. A lower absorption is obtained with a dynamic compaction at 10% cement content than that with 15% of cement without compaction. A similar trend was observed when static compaction using an 8.2 MPa stress was used and water absorption decreases from 14.3% to 10% and 6.6% for respectively 0%, 5% and 10% of cement content (Table 5). However, the static compaction was less efficient than the dynamic compaction in reducing

Table 3
Total water absorption of cement-stabilized specimens

Cement content (%)	2	4	6	8	10	15
Absorption coefficient (%)	–	–	13.68	14.95	16.60	16.96

Table 4
Effect of cement content on water absorption by capillary

Cement content (%)		5	10	15
Absorption coefficient (%)	1st cycle	12.67	11.20	6.00
	2nd cycle	28.94	28.94	11.33

Table 5
Comparison of absorption by capillary obtained with static and dynamic compaction

Cement content (%)		0	5	10
Absorption coefficient (%)	Static compaction	14.29	10.0	6.56
	Dynamic compaction	11.92	9.76	2.71

the water absorption. The positive effect of the combination of chemical and mechanical stabilisation seems to have on one hand cemented the soil particles together and filled in the pore space in the soil and on the other hand prevented the reorientation and flocculation of soil particles, which precluded formation of enlarged pores and cracks [24].

The higher water permeability and higher water absorption and the lower strength after immersion in water could be improved by treating the surface with cement render with polymers or cement–lime renders especially when the construction is to be exposed to water [8].

4.3.3. Accelerated erosion tests

The results of accelerated erosion tests show a complete disintegration of the non-stabilised specimens. The effect on compacted stabilised specimens show no visible distress sign on the surface and hence it was difficult to assess the effect of different compaction methods.

5. Conclusion

A local clay sandy soil was stabilised either chemically by cement or mechanically by static, dynamic and vibro-compaction or both chemical and mechanical stabilisation. Mechanical stabilisation by dynamic compaction seems to give better results as compared to static or vibro-static compaction. A better compressive strength at the dry state and after 48 h of immersion in water was obtained with chemical stabilisation at cement content higher than 8%. Optimal water content should always be sought to get higher strength and higher durability. The high decrease in compressive strength after 48 h of immersion in water even with dynamic compaction and higher cement content indicates the importance of appropriate building design avoiding a direct contact of stabilised soil blocks with water such as rainwater in humid regions.

Acknowledgement

Contribution of Dr. Arab, A. and Dr. Melbouci, B. of the University of Tizi-Ouzou to the experimental work is highly appreciated by the authors.

References

[1] CNERIB. In: Proceedings of Maghrebin Symposium on Development of Construction with Local Materials: MATLOC 91, 3–5 December 1991, Biskra, CNERIB, Ministry of Housing, Algeria, 1991. p. 209.

[2] Goumari F. Matériau en terre crue compactée: amélioration de sa stabilité à l'eau. Doctorate thesis, INSA de Lyon, 1989.

[3] Cherif I, Kenai S, Matib M. Perspectives d'une maçonnerie renforcée à base de matériaux locaux. In: Proceedings of Maghreb Conference on Local Construction Materials (MATLOC 91), 3–5 December 1991, Biskra, Ministry of Housing, Algeria, 1991. p. 145.

[4] Melbouci B. Influence du mode de compactage sur les caractéristiques du béton de terre stabilisée. Annales de l'Institut Technique du Bâtiment et des Travaux Publics, No. 490, Paris, France, January 1991. p. 50.

[5] Benazzoug M. Contribution à l'étude des géobétons: influence des principaux procédés de stabilisation sur les propriétés physiques et mécaniques. Master thesis, Civil Engineering Department, University of Tizi Ouzou, Algeria, 2001. p. 170.

[6] Guettala A, Mezghiche B, Chebili R, Houari H. Durability of lime stabilised earth blocks. In: Dhir RK, Dyer TD, Holliday JE, editors. Proceedings of the International Congress: Challenges of Concrete Construction: Sustainable Concrete Construction, Dundee, September 2002. Thomas Telford; 2002. p. 648–54.

[7] Bartali H. La terre armé de paille pour les constructions. In: Proceedings of the French-Maghreb Symposium on Construction with Local Materials, Marseille, France, October 1991. p. 551.

[8] Bouhicha M, Aouissi F, Kenai S. Performance of composite soil reinforced with barely straw. Int J Cem Concr Compos, special theme issue, natural fibre reinforced cement composites, in press.

[9] CNERIB. Recommandations pour la production et mise en œuvre du béton de terre stabilisée, CNERIB, Algiers, Algeria, 1993. p. 33.

[10] CNERIB. Guide technique du béton de terre stabilisée, CNERIB, Ministry of Housing, Algiers, Algeria, 1994. p. 55.

[11] Gresillon JM. Etude sur la stabilisation et la compression des terres pour leur utilisation dans la construction. Annales de l'ITBTP, No. 339, Paris, May 1976. p. 22–3.

[12] Gresillon JM. Etude de l'aptitude des sols à la stabilisation au ciment application à la construction. Annales de l'ITBTP, No. 361, Paris, May 1978. p. 2–8.

[13] Kouidri Z. Contribution à l'étude de stabilisation d'un sol sableux: Modélisation du comportement mécanique. MSc thesis, University of Laghouat, Algeria, 2000. p. 113.

[14] Houben H, Guillaud H. Traité de construire en terre: l'encyclopédie de la construction en terre, CRATerre, vol. 1, Edition Parenthèse, Paris, 1989.

[15] Doat P, Hays A, Houben H. Construire en terre, collection d'architecture, Paris, 1981.

[16] Ghavami K, Filho RDT, Barbosa NP. Behaviour of composite soil reinforced with natural fibres. Cem Concr Compos 1999;21:39–48.

[17] Aouissi F. Comportement physique et mécanique de l'adobe paillé. MPhil thesis, University of Laghouat, Algeria, June 2000. p. 111.

[18] RILEM TC 153-CIB W90 CEB. Technologie du bloc de terre comprimée. Modes opératoires pour les essais d'identification en laboratoire des terres, Provisional document, October 1995.

[19] Winterkorn HF, Fang HY. Foundation engineering handbook. London: Van Nostrand Reinhold; 1975.

[20] Akoto BKA, Singh G. Some geotechnical properties of a lime-stabilized laterrite containing a high proportion of aluminium oxide. Eng Geol 1981;34:185–99.

[21] Consoli NC, Prietto PDM, Carraro JAH, Heineck KH. Behaviour of compacted soil-fly ash-carbide lime mixtures. J Geotech Geonviron Eng 2001:774–82.

[22] Stulz R, Mukerji K. Appropriate building materials. Switzerland: SKAT Publications; 1988.

[23] CRAterre. Soil block presses: product information. France: CRAterre; 1988.

[24] Borderick GP, Daniel DE. Stabilizing compacted clay against chemical attack. J Geotech Eng 1990;116(10):1549–67.