Role of Cement Science in Sustainable Development

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THEME 3 SUPPLEMENTARY CEMENTING MATERIALS, ACTIVATORS AND INHIBITORS

DURABILITY OF CEMENT AND CEMENT PLUS RESIN STABILISED EARTH BLOCKS

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ABSTRACT. The main drawback of earth construction is the rapid deterioration of the material under severe weather conditions. The objective of this work is to improve the behaviour of stabilized blocks of earth blocks against water attacks. The blocks manufactured with one type of earth were tested in compressive strength as dry blocks and after immersion, in intensive sprinkling and in absorption. Tests of wetting-drying and tests of freeze- thaw were also carried out. The results show the influence of the different manufacturing parameters: compacting intensity, sand, cement and cement plus resin content on the mechanical strength in the dry state as well as in the wet state, water resistance coefficient, weight loss and absorption.

Keywords: Stabilized, Cement, Resin, Earth, Compacting stresses, Sand content, Compressive strength, Water resistance coefficient, Wetting-drying, Freeze-thaw, Absorption, Durability.

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INTRODUCTION

The use of earth as a building material dates back to the period of the ancient Mesopotamia (5000-4000 B.C). For economical reasons and by studying what already has been done until now, scientists and builders consider that it is judicious to try to improve the life span of construction materials [1], [2]. Large research programs have been undertaken all over the world into the durability of earth walled buildings [2], [3], [4]. The durability prevision of stabilized earth blocks is still a controversial matter amongst construction actors. In order to know the limits of this kind of material destined to construction, it is intended to find solutions that can improve its life span by the know how of its general use as well as its mass treatment (additions of binders, compacting energies,...). Obtaining a durable material would need a treatment which would result in sufficient mechanical strength as well as low sensitivity to water attacks [5].

These two main conditions should be preceded by a very precise study of parameters related to the grading and mineralogy of these materials. The type and the content of the binders, aggregates grading, compacting stresses and water content would be adapted as conditions of making of these materials [6], [7]. The durability can be improved by other additions such as lime [5], cement and lime or cement and microsilica [8]. In this present work, we have tried to improve the durability of earth blocks by several methods: by the additions of cement (5, and 8 %), cement and resin (5 % cement + 50 % resin; 8 % cement + 50 % resin(1)), sand content (0, 10, 20, 30 and 40%) and the compacting stresses (5, 7.5, 10, 12.5, 15, 17.5 and 20 MPa).

(1) The resin content is relative to compacting water.

PHYSICAL CHARACTERISTICS OF SOIL

Soil samples of the region of Biskra (south east of Algeria) have been taken as reference samples and subjected to several laboratory tests as specified by ASTM standards [9].

Atterberg Limits

According to [11], the best earth soils for stabilization are those with low plasticity index (P.I) and the product (P.I x M) in the vicinity of 500 to 800, where M is the percentage of mortar, in this case P.I x M = 644, see Table 1.

Table 1 Atterberg's limits.

SOIL CHARACTERISTICS							
Sample	W_L	W_P	P_I	Ws	Wa	Ca	PIxM
No 1 Biskra	31 P.Z(1)	17 P.Z	14 P.Z	10 P.Z	9.5	0.77 A.A(2)	644

(1) Preference Zone.
(2) Average Activity.

Grading Aggregate Analysis

In Figure 1, the grading curves of the soils as well as the corrected soils with sand and limits of the recommended zone for compressed earth blocks are represented [10]. It is noted through these curves that soil and corrected soil with contents of 10, 20 and 30 % of sand are very close to the lower limit of the recommended zone; whereas the corrected soil with 40 % sand content is out of the recommended limit zone.

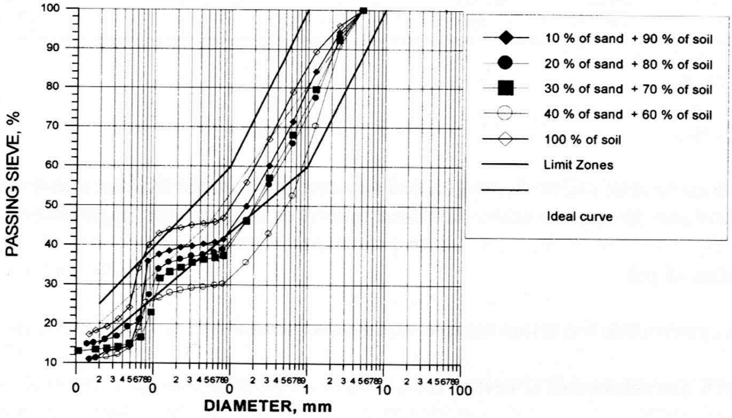


Figure 1 Grading curves aggregate analysis of used soil, corrected soil and the recommended limit zone of stabilized earth concrete.

Chemical Analysis

Clay analysis has been accomplished in the cement factory of Hamma Bouziane (Constantine, East of Algeria) using X ray Fluorescence, in accordance to NF6 P 15-467. The obtained results, showing the constituents of the soil, are presented in Table 2.

Table 2 Chemical composition of the soil.

SAMPLE	CONTENT, %					
	SiO_2	AL_2O_3	Fe_2O_3	MgO	CaO	SO_3
No 1	32.22	2.24	0.53	0.03	31.8	5.81

SAMPLE	CONTENT, %					
	K_2O	Na_2O	Cl	TiO_2	MnO	F.W(1)
No 1	0.15	0.03	0.005	0.2	0.02	26.9

(1) loss due to fire.

Mineralogical Analysis

To differentiate the clay soils, a mineralogical analysis by X rays is important. The analyses have been carried out in the geology laboratory of Boumerdes (Algiers, Algeria) using a SIEMENS 500 diffractometer, interfaced to a computer for data collecting.

Resin

The resin used for this work has a commercial name of 'Medalatex'; supplied by Granitex; a private Algerian company of additives making. Medalatex is an aqueous dispersion of resin of white colour. It's compatible with most cements as well as lime.

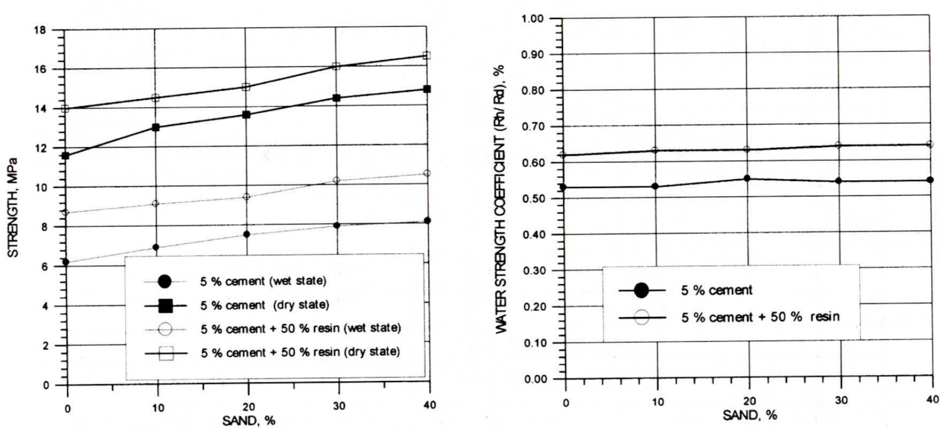
In general, the latex content varies between 10 and 20% in respect to the cement mass. The latex addition gives a good adherence to the support. It gives also the impermeability, the durability and the improvement in protection of the reinforcement, thus resistance to chemical attacks.

INFLUENCE OF SAND CONTENT

In order to determine the influence of sand content on the mechanical strength, durability and the optimal quantity of soil-sand mix, several blends have been used (0 – 40%) with cement contents of 5% and 5% + 50% resin and a compacting stress of 10 MPa. Samples have been stored in a humid environment.

Compressive Strength

Figure 2a shows that the compressive strength of dry and humid sand-soil samples increases with increasing sand content. However, in percentage terms, the compressive strength evolution is 27.5% for dry samples and 30 % for humid samples, when the concentration of sand is 30%. For the same sand content, the addition of the resin has resulted in the increase in strength of the order of 11% in the dry state and 29% in the wet state.



a) Mechanical strength

b) Water strength coefficient

Figure 2 Sand content influence on compressive strength and water strength coefficient with 5 % cement and 5 % cement + 50 % resin stabilizer, using 10 MPa compacting stress.

Tests have been conducted on aggregates passed on 80 microns sieves. The obtained results in Table 3 show that the soil is composed mainly of kaolin (non-expansive and non-absorbent) and illites.

Table 3 Mineralogical constituents of the soil

Sample	CLAYEY MINERALS, %			NON CLAYEY MINERALS, %	
	Kaolin	Illites	I. M[(1)]	Quartz	Calcite
N 1	45	40	15	5	10

[(1)] Interstratifiers.

Organic Matter

During the treatment of soil with oxygenated water, it was noticed that the soil-water reaction was very slow and the organic mater was essentially free of vegetable fragment (0.15%).

Measurement of pH

The analysis shows that the tested sample was almost neutral, pH = 7.1.

Mechanical Characteristics (Proctor test)

The results are shown in Table 4.

Table 4 Proctor test

	OPTIMAL (Wc), %	MAX. DRY DENSITY (γ), kg/m^3
	11.75	1877
Appreciation	Excellent	Satisfactory

The Proctor test shows that the water content (Wc) of the studied sample is excellent and the dry density is satisfactory.

Physical Characteristics of Sand

Using AFNOR [12] regulations, the sand samples have been tested and found the following results :

- Disturbed apparent density (ρo) = 1520 kg/m^3
- Specific mass (γ) = 2640 kg/m^3
- Fineness modulus (F.M) = 2.33
- Sand equivalence value by sight (SE) = 70
- Sand equivalence value by test (SE_t) = 64

Cement

The cement used was manufactured in Algeria, under the commercial label C.P.J 45 and has been tested following the AFNOR [12] regulations in order to determine its real class. Tests carried out on mortar cubes have shown that the strength at 28 days was 46 MPa.

Resin

The resin used for this work has a commercial name of 'Medalatex'; supplied by Granitex; a private Algerian company of additives making. Medalatex is an aqueous dispersion of resin of white colour. It's compatible with most cements as well as lime.

In general, the latex content varies between 10 and 20% in respect to the cement mass. The latex addition gives a good adherence to the support. It gives also the impermeability, the durability and the improvement in protection of the reinforcement, thus resistance to chemical attacks.

INFLUENCE OF SAND CONTENT

In order to determine the influence of sand content on the mechanical strength, durability and the optimal quantity of soil-sand mix, several blends have been used (0 – 40%) with cement contents of 5% and 5% + 50% resin and a compacting stress of 10 MPa. Samples have been stored in a humid environment.

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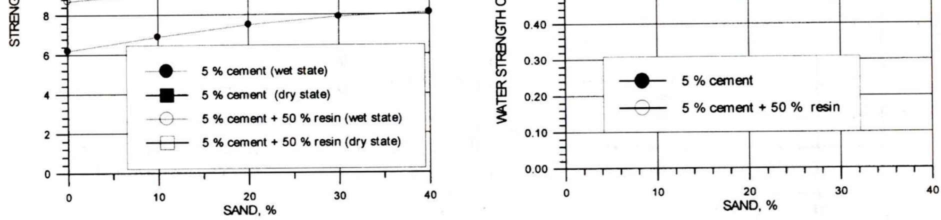


a) Mechanical strength b) Water strength coefficient

Figure 2 Sand content influence on compressive strength and water strength coefficient with 5 % cement and 5 % cement + 50 % resin stabilizer, using 10 MPa compacting stress.

Compressive Strength in Humid Samples

The mechanical strength of humid soil sample increases with increasing the compacting stresses, Figure 3a. The compressive strength also increases with the addition of resin. Like in the case of dry samples, the compressive strength evolution is not regular. The effect of the resin addition is more important in the case of the 5 % sample.

Water Strength Coefficient

The water strength coefficient evolution depends on the cement and cement plus resin percentage and on the compacting stresses, Figure 4b. It increases with the increase of cement content, the compacting stresses as well as the addition of resin. For example, the addition of the resin by 50 % as is the case in this work had resulted in variation of the water strength coefficient by 15 % and 7.5 % for both cases of 5 % and 8 % cement respectively, with a compacting stress of 15 MPa.

Water Absorption

The absorption capacity of earth stabilized blocks gives a general idea on the presence and importance of voids. When a volume of soil is subjected to the action of a stress, the material is compressed and the voids ratio decreases. As the density of soil is increased, its porosity is reduced and less water can penetrate it [13].

Total Absorption

The present test consists of immersing the soil samples in water and measuring the increase in weight during 24 hours. The absorption is evaluated in dry weight percentage. Table 5 shows that the absorption decreases when increasing the compacting stresses. Up to a certain value of 15 MPa and above; it has a minor effect. We also notice that the increase in cement content lowers the water absorption factor. The resin addition lowers considerably the water absorption factor for both cement contents. The total absorption varies between 18 to 33 % and between 18 to 39 % for 5 and 8 % cement respectively; for the compacting stresses varying from 5 to 20 MPa.

Table 5 Influence of the compacting stresses and the cement and cement plus resin content on the total absorption

	TOTAL ABSORPTION, %			
Compacting stress (MPa)	5% cement	5% cement + 50 % resin	8% cement	8% cement + 50 % resin
5	10.12	8.2	9.17	7.5
7.5	9.78	7.5	9.23	6.6
10	9.12	6.1	8.26	5.5
12.5	8.33	6.0	7.84	5.6
15	8.27	5.9	7.35	5.3
17.5	7.54	5.8	7.25	5.2
20	8.71	5.8	8.59	5.2

Water Strength Coefficient

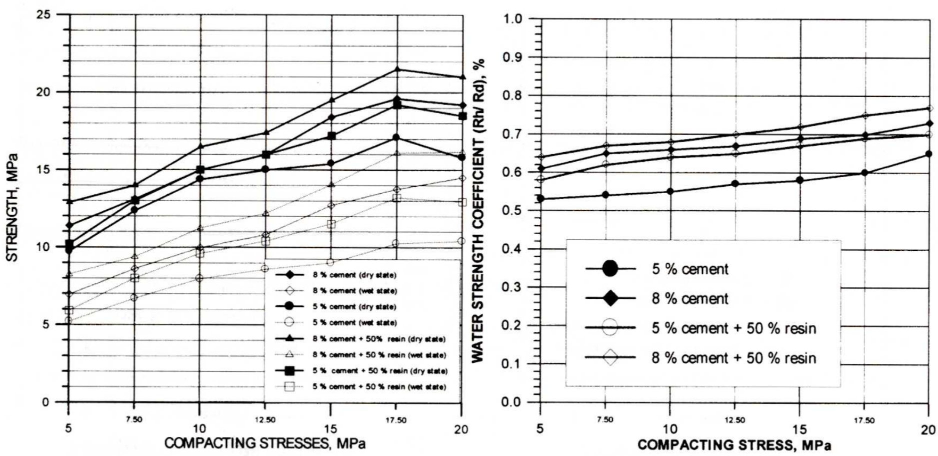
The water strength coefficient is determined from the compressive strength ratio for dry and humid states. Figure 2b shows that the sand content does not affect the water strength coefficient which varies between 0.53 and 0.54 when the sand content varies between 0 and 40%. However, the addition of the resin has resulted in an increase of the coefficient of the order of 17 %.

INFLUENCE OF THE COMPACTING STRESS AND THE CEMENT AND CEMENT PLUS RESIN CONTENT

In the following section, the effect of the compacting stresses (5, 7.5, 10, 12.5, 15, 17.5 and 20 MPa), the cement content (5 and 8 %) and cement plus resin (5 % + 50 % and 8 % + 50 %) on the compressive strength on dry and humid sand samples is studied. In addition, durability tests of wetting and drying, freeze-thaw, water absorption (total and capillary) tests with the optimal sand content of 30% are carried out.

Mechanical Compressive Strength in Dry Samples

Figure 3a clearly shows that the compressive strength evolution is the same for the different cement and cement plus resin content: the compressive strength increases with increasing the compacting stress until 17.5 MPa which is the optimal compacting stress. Again, the addition of the resin had a great effect on the strength of the samples in the dry state. As can be seen in Figure 3, the compressive strength increases with the addition of resin content for both cement content cases.



a) Compressive strength b) Water strength coefficient

Figure 3 Influence of compacting stresses and cement and cement plus resin content on the compressive strength.

Capillary Absorption

Capillary absorption test consists of placing the soil sample on a humid surface with voids, constantly water saturated, and measuring its weight after 7 days. Absorption is evaluated in percentage of dry weight. Table 6 shows that the capillary absorption decreases when increasing the compacting stresses and the cement as well as cement plus resin content. For instance, it varies from 2.15 to 2.02% when the cement content varies from 5 to 8% with a compacting stress of 17.5 MPa. Again, the addition of the resin decreases considerably the water capillary absorption.

Table 6 Influence of the compacting stresses and the cement and cement plus resin on the capillary absorption

	CAPILLARY ABSORPTION, %			
Compacting stress (MPa)	5% cement	5% cement + 50 % resin	8% cement	8% cement + 50 % resin
5	3.99	3.8	3.52	3.1
7.5	3.19	3.7	2.48	2.2
10	3.90	3.1	2.30	2.1
12.5	2.74	2.5	2.24	1.9
15	2.35	2.3	2.23	1.8
17.5	2.15	2.1	2.02	1.2
20	1.17	2.0	1.19	1.1

Wetting and Drying Test

This test is carried out according to the ASTM D 559-57; it consists of immersing soil samples in water for a period of 5 hours and then removing to be dried in an oven at 71 °C for a period of 42 hours. The procedure is repeated for 12 cycles, samples are brushed every cycle to remove fragments of the material affected by the wetting and drying cycles. For every sample, the variation in weight is computed after the 12 cycles [13]. Table 7 shows that the loss in weight diminishes when increasing the compacting stress and the cement and cement plus resin content. For the cases of 5 and 8% cement, the effect of cement on the weight loss is important for the compacting stresses up to 12.5 MPa. Above this value the addition of cement is less significant. The resin addition has a slight effect on the weight loss.

Table 7 Influence of the compacting stresses and the cement and cement plus resin on the weight loss.

	WEIGHT LOSS, %			
Compacting stress (MPa)	5% cement	5% cement + 50 % resin	8% cement	8% cement + 50 % resin
5	2.65	2.1	2.07	1.8
7.5	2.28	1.8	1.86	1.7
10	1.9	1.5	1.4	1.2
12.5	1.34	1.2	1.35	1.3
15	1.27	0.9	1.17	0.9
17.5	0.31	0.25	0.25	0.22
20	0.13	0.10	0.05	0.05

Freeze - Thaw

Following the procedure described by ASTM D560, the freeze-thaw test consists of placing a soil sample on an absorbent water saturated material in a refrigerator at a temperature of -23°C for a period of 24 hours and then removed. The sample is then thawed in a moist environment at a temperature of 21°C for a period of 23 hours and then removed and brushed. The test is repeated for 12 freeze-thaw cycles and then dried in an oven to obtain a constant weight [13]. Table 8 shows that the weight loss diminishes when increasing the compacting stress and the cement content as in the case of wetting and drying test discussed previously. For the 5% cement sample, the weight loss changes from 17 to 3.3% when the compacting stress varies from 5 to 20 MPa. And the weight loss is very important with low compacting stresses. The effect of the resin is more pronounced at lower compacting stresses.

Table 8 Influence of the compacting stresses and the cement and cement plus resin on the weight loss

	WEIGHT LOSS, %			
Compacting stress (MPa)	5% cement	5% cement + 50 % resin	8% cement	8% cement + 50 % resin
5.0	17.0	3.8	5.28	4.1
7.5	12.0	3.7	4.67	3.2
10.0	4.5	3.1	2.4	2.1
12.5	4.2	2.5	1.3	1.1
15.0	3.9	2.3	1.02	1.0
17.5	3.6	2.1	0.24	0.2
20.0	3.3	2.0	0.14	0.1

CONCLUSIONS

The main objective of this work was to investigate the different factors affecting the durability of cement stabilized earth blocks as well as the importance of the resin addition.
The work showed the importance of the sand content, the compacting stress and the cement and the cement plus resin contents on the behaviour of stabilized earth blocks with respect to water attacks as well as elucidating certain points:

- The principle effect of the stabilization with the cement is to prevent water attacks. We would achieve good stabilization if we could obtain a durable material with a limited loss in mechanical strength in a wet state [14].
- The sand content does not affect considerably the compressive strength and the water strength coefficient.
- Increasing the compacting stress from 5 to 20 MPa and the cement content from 5 to 8% improves the compressive strength in dry as well as wet state and the water strength coefficient. We notice also that the increase of these two parameters decrease the weight loss and the water absorption.
- The latex addition is shown also to be beneficial concerning the durability in general. This is due to the fact that such additions consolidate the cementitious matrix and play a role of a co-matrix. However, when considering the economical factor, mainly the resin price (4 to 6 times more expensive than cement), this addition is not recommended.

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Celebrating Concrete: People and Practice

Role of Cement Science in Sustainable Development

An International Symposium dedicated to Professor Fred Glasser, University of Aberdeen, UK

Portland cement concrete is arguably the most important construction material used today. However, to maintain its unrivalled place within the construction industry, the driving force of concrete, namely cement, must embrace all environmental issues, whilst still achieving desired long-term performance. This is vital to ensure that the use of natural resources is minimised and value added sustainable cementitious products are derived from existing waste materials.

Role of Cement Science in Sustainable Development forms the Proceedings of the two day International Symposium dedicated to Professor Fred Glasser, University of Aberdeen UK. The event, organised by the Concrete Technology Unit, University of Dundee was held during Celebrating Concrete: People and Practice, 3-4 September 2003. The Symposium deals with such issues as modern cement manufacture, hydration of Portland cement, supplementary cementing materials and special and non-Portland cements.

Professor **Ravindra K Dhir** OBE
founding Director of Concrete Technology Unit at the University of Dundee is renowned as a scholar and practitioner in the field of concrete science, technology and construction. He was awarded an Honorary Fellowship of the Institute of Concrete Technology in 1994 and appointed an Officer of the Order of the British Empire in 1999 for services to concrete technology.

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