An experimental study of a desert dune sand-cement-calcareous fillers based micro concrete

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ABSTRACT: Dune sand exists in large quantities in a lot of Arabic countries. For instance sixty percent of Algerian territory is covered by this type of sand. In order to exploit this important deposit to achieve a low cost concrete, an experimental investigation was carried out using the same amount of cement as in ordinary concrete. The objective was to replace the alluvial or pit sand and also the coarse aggregate having an excessive coast by this locally available material.
It has been found that the dune sand can be used successfully to constitute a skeleton of a concrete when a judicious choice is made on its composition. An ultimate compressive strength of 15-20 MPa can be obtained. A good bonding with steel has been noted through the pull out test. The behaviour in flexure, studied on a true prototype reinforced dune sandcrete beam, was in general found to be the same as in the ordinary concrete.

1- INTRODUCTION

The idea of promoting the technology of the sandcrete by the enhancement of natural dune sand was born according to several observations:
- Abundance of the raw materials: Dune sand is very abundant in many Arabic countries with almost unexhausted quantities. In Algeria for example, it covers about 60% of the territory.
- Tendency of alluvial and quarry aggregates for the rarefaction means higher coast: The price of one tonne of aggregates has known in Algeria a considerable increase, from 25 DA in 1980 to 300 DA in 1993, 2500 DA in 1999 and 9000 DA in 2009!. If we know that the aggregates take part of traditional concrete with a proportion approximately of 75 %, we realise clearly the price increase in the traditional concrete.
- Excessive cost of aggregates transport: In some countries with poor supply in aggregates or having bad repartition of resources, the aggregates have to be transported over long distances. Stamapoulos and Kotzias (1971) have reported the case of 2 constructions, one in the Arabian golf and the second in the Maghreb (the authors do not give more preciseness about the exact sites), where constructors

facing the lack of aggregates and isolation of building sites with respect to the aggregates supplying places (hundreds of km) have replaced successfully the required aggregates by the desert local available sand. They have avoided costly transport and deadlines.

- Economy of use: The constructions with few stories, such as the case of those existing in the Arabic countries, are mechanically lightly loaded. When they are projected in the sites where dune sand is abundant, sandcrete could favourably replace the traditional costly concrete.
- Design: Because of its small gradation, dune sandcrete allows the realisation of architectonic effects and gives nice and attractive surfaces. Lighthouse of Port-Said in Egypt is a perfect illustration.

Based on this, sandcrete could be considered as the right substitute when, for specific use, its formulation gives equivalent rheological and mechanical characteristics to those of traditional concretes. In what follows, test results on dune sand of Laghouat city region (400 km south Algiers) and on concrete having the skeleton of this sand will be exposed.

2- RAW MATERIALS

The dune sandcrete projected was a mixture of four materials: natural dune sand, Portland cement in the same proportions as in a traditional concrete, fillers and ordinary mixing water.

2-1 The dune sand

The aggregate gradation as determined by using standard sieves (NFP 18 304) ranges from fine to medium (figure 1). The calculated grading modulus was M_f = 1.20 (2.20 to 2.80 for sands used in traditional concrete). It can also be seen that the dune sand material used is continuously graded.

The relative density was M_v = 1480 kg/m^3 when the absolute density as measured by water picnometry was M_s = 2630 kg/m^3.

The total porosity has been determined by the following relationship (1) and has been found equal to 44 %.

$$P(\%) = 100(M_s - M_v)/ M_s \quad (1)$$

The sand's equivalent as measured by the NFP 18 598 standard was E_s = 89. It proves that the dune sand employed is very clean and contains a very few fine dust or clayey elements.

Concerning the possible existence of noxious components inside the studied dune sand, the chemical analysis has shown (table 1) that it contains sulphates, sulphurs, chlorinated and organic matters in very little quantities.

Sulphates (generally calcium sulphate $CaSO_4$) are chemical components which can highly affect the quality of the concrete as they react with the aluminates contained in the cement (see equation 2).

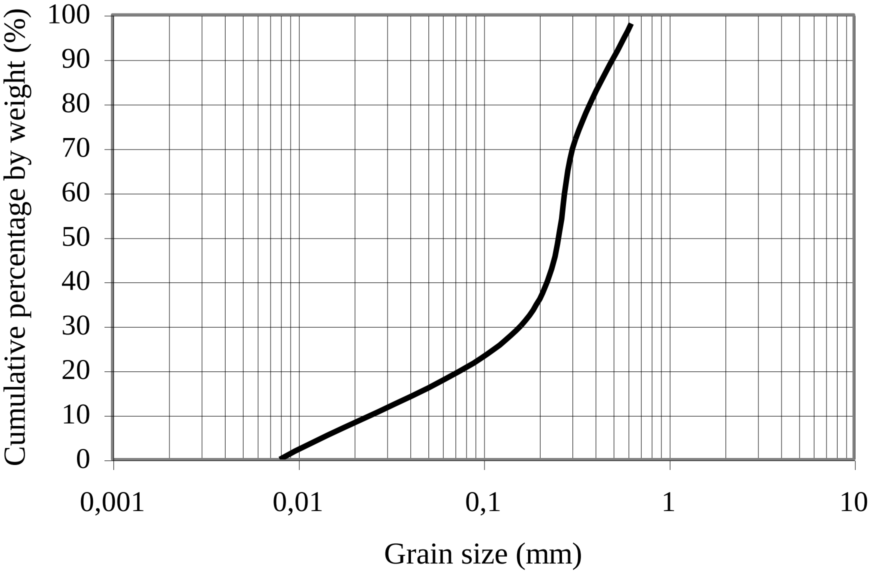

Figure 1: Aggregate Grading Curve

Table 1: Chemical Analysis of Dune Sand

Noxious component	Rate (%)
Sulphates and sulphides (SO_3^{--})	0.91
Ions chlorides	0.0007
Organic matters	-

$$3CaO.Al_2O_3.6H_2O + 3CaSO_4 + 25H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O \quad (2)$$

The obtained product (calcium hydro-sulpho-aluminate) in crystallising causes internal stresses within the concrete, therefore, mechanical disintegration takes place. On the other hand, the contact of these sulphates with the steel reinforcement of concrete provokes corrosion and then a progressive decline of the mechanical resistance of concrete steel system.

The studied sand contains less than 1% of sulphite (SO_3^{--}), 0.91% exactly. This ratio corresponds to moderated aggressive degree according to the NFP 18 301 standard.

2-2 The cement and the mixing water

An Ordinary Portland Cement manufactured in Algeria, commercially named CPA 210-325 has been used in this work to ensure the chemical stabilisation. Its density is 2.95 and its Blaine's specific surface area is 3300 cm^2/g. The mixing water added to react with the cement is normal tap water with pH ~ 7.5.

2-3 The fillers

The fillers have been added to the basic composition to correct the natural compacity of the dune sand and so to improve the projected sandcrete performances. They consist of a crushed waste collected from a disused quarry situated at Djebel Dakhla, in the Laghouat area. It is primarily composed of calcite (97% of $CaCO_3$) and will permit the creation of an epitaxical link with the cement according to Unikowsky (1981). The specific density is of 2900 kg/m^3. The specific surface (as measured according to the standard EN 196-6) is of 3120 cm^2/g (Bederina et al 2005) and (Bederina et al 2007).

Figure 2 shows the grain size distribution obtained by using the sedimentometric method. It can be noted that the fillers are continuously graded. Moreover, the chemical analysis has shown the non existence of noxious elements, only a small rate of sulphate has been detected witch is generally accepted by several standard recommendations (SO_3^{--} = 0.83% < 1%).

The water absorption capacity C = W/F = 0.28 characterising their avidity in water is about the same as that of the traditional hydraulic binder when referring to Guinez (1984): Glass marbles (0.00), Fly ash (0.17), Cement (0.27), Lime (0.28) and Iron oxide (0.44).

E: mass of absorbed water (gr)

F: mass of fillers used in the experiment (120 g according to NFP 18 554 standard)

From this point of view, the used fillers will not create any particular problem towards the dune sandcrete workability or its bleeding.

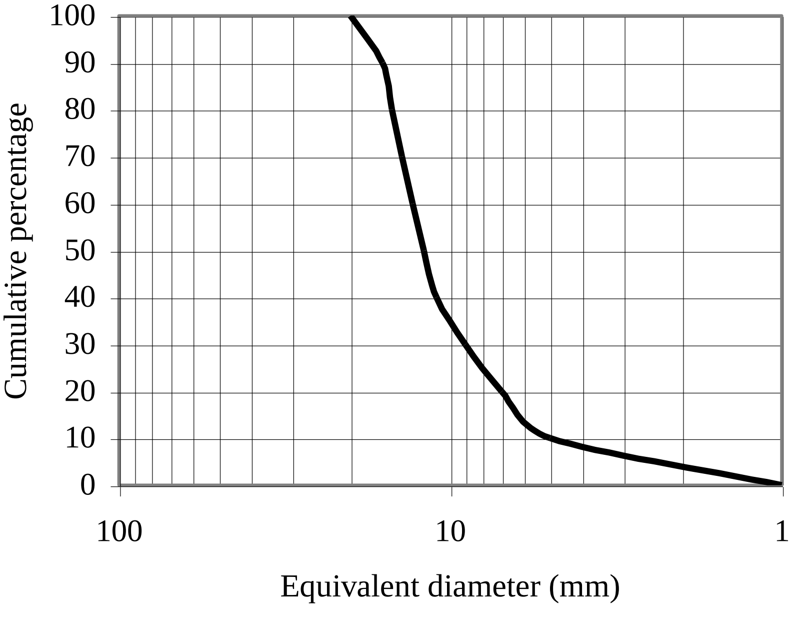

Figure 2: Grain Size Distribution of the Fillers Employed

3- FORMULATION OF THE DUNE SANDCRETE

Since there is no proper method of finding a formulation, its use becomes a basic problem faced up in this study. The principal authors having studied this material have based their approaches exclusively on the trial (Couret 1982) or on successive approximation (Delude 1984).

This problem is related, in our opinion, to the multitude of parameters which characterise the components of this concrete (nature and sand gradation analysis, nature and fineness of fillers etc...) and also to the multitude of the objectives aimed at by the authors. It seems like no approach based on the behaviour of sandcrete towards the traditional W/C ratio or the W/(C + F) ratio characterising the water content of the mix has been proposed. For this purpose we have tried to exploit these different approaches results to determine the optimal composition of the projected sandconcrete. This latter must have a mean compressive strength ranging from 15 to 20 MPa and plastic workability to make easier its implementation.

The methodology adopted herein is based on the criteria of finding a maximal compacity, containing two variants and inspired from sandcrete studies conducted by Chauvin (1988). The author has fixed the cement proportion and defined the required quantity of fillers to obtain the maximal compacity and strength of his projected concrete. He has concluded that whatever type of sand used, concrete density (then compacity) increases with the increase of the quantity of fillers. Otherwise a gain in compacity is usually followed by a gain in strength.

Based on this observation, the maximum of fillers has been fixed in this work to 300 kg/m^3 for 2 variants of composition in order to reach the corresponding maximum strength:

- Variant 1: Variation of W/C ratio from 0.80 to 1.20 (step = 0.05)
- Variant 2: Variation of W/(C + F) ratio from 0.40 to 0.60 (step = 0.05)

The resulting compositions are well detailed by Benmalek (1997). Among 42 tested compositions, the adopted one for the conducted study herein was:

- Dune sand: 1249 kg/m^3
- Portland cement: 350 kg/m^3
- Calcareous filler: 300 kg/m^3
- Mixing water: 281 l/m^3

The main sandcrete material characteristics are: Compressive strength = 17.76 MPa, Slump = 8.55 cm in Abrahams's cone corresponding to a plastic mix and a relative density at dry condition = 2130 kg/m^3.

4- BEHAVIOUR OF THE HARDENED ELABORATED SANDCRETE

4-1 Stress-Strain evolution

The evolution has been followed on cylindrical standard specimens of 16 cm x 32 cm dimensions using normal testing speed. Figure 3 shows the increase of the relative deformation with respect to the increase of the loading stress. It can be observed that the stress-strain curve is reasonably linear at low stress levels. The maximum stress is reached at a compressive strain of ~ 2000 μm.

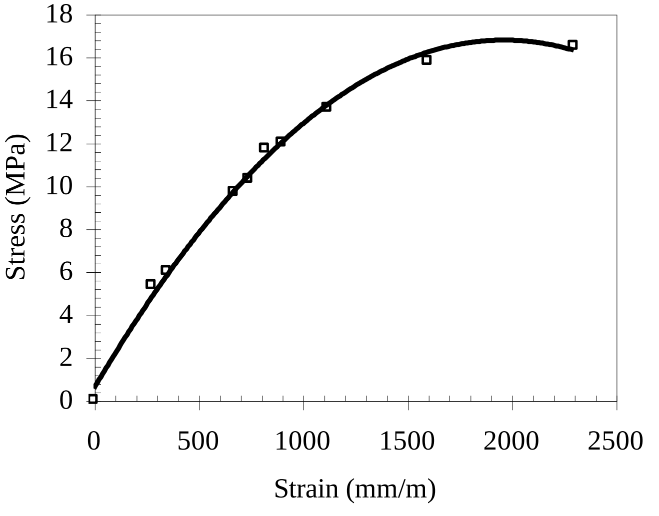

Figure 3: Stress-Strain Curve

The modulus of elasticity, usually taken as the slope of the tangent through the origin at the initial portion of the stress-strain curve, has been calculated and was found E = 21000 MPa. This value is closer to that of microconcretes obtained by Gorisse (1972) than that of traditional concretes which is generally about 30000 MPa. Gorisse has effectively obtained E = 22000 MPa for a microconcrete having a maximum diameter of grains equal to 1.6 mm and E = 26000 MPa for a microconcrete having the same compressive strength (20 MPa) and a maximum diameter of grains equal to 5.0 mm.

4-2 Bonding with steel

This test was carried out to see if both dune sandcrete and rebars can act correctly together and if the bond stress at failure defined by the following relation (3) is similar to that obtained usually on traditional aggregate concretes.

$$\tau = \frac{dF/dx}{U} = \frac{1}{U} \text{ x } \frac{dF}{dx} = \frac{1}{\pi\phi} \text{ x } \frac{dF}{dx} \tag{3}$$

Where: dF = the unit length variation due to the axial tension force applied on the steel bar, dx = the finite element length, U = the useful perimeter of the steel bar and ϕ, the diameter of steel bar. This stress could be written as (4) when it is supposed constant along the total adhesion length.

$$\tau = \frac{1}{\pi\phi} \text{ x } \frac{F}{l} \tag{4}$$

The figure 4 exhibits the specimen used and the schematic of test. The 4 bars of 6 mm diameter have been placed into the specimen to avoid its premature failure by tension. On the other hand, the second bar with L_2 = 20 cm serves as barwitness.

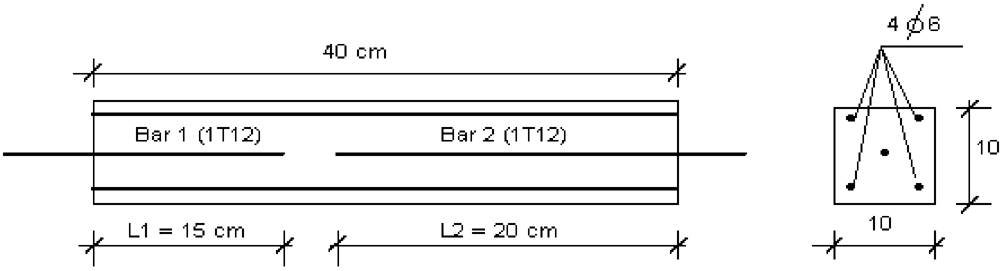

Figure 4: Schematic of Test

The mean failure load of adhesion as measured on 3 same samples has been equal to 38.4 KN and corresponds to a mean calculated bond stress τ = 6.77 N/mm^2. Those of usual concretes range from 3 to 9 N/mm^2 according to Renaud (1978).

From this point of view one may be easily concluded that sandcrete agree well with the usual steel bars employed in building construction.

4-3 Flexural behaviour

The adopted scheme presented in the figure 5 allows eliminating the shear effect in the central area, aim of this study. The specimen tested (figure 6) was a true prototype reinforced dune sandcrete beam. Its dimensions were 12.5 cm x 22 cm x 220 cm. The support areas have been intentionally reinforced with ϕ8 stirrups to avoid a premature failure of the beam by shearing.

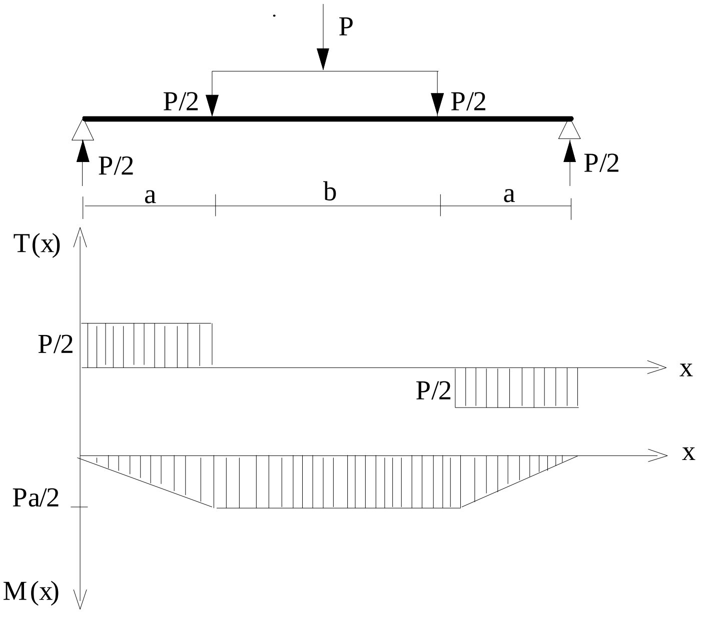

Figure 5: Test Schematic, Shear T(x) and Bending M(x) Diagrams

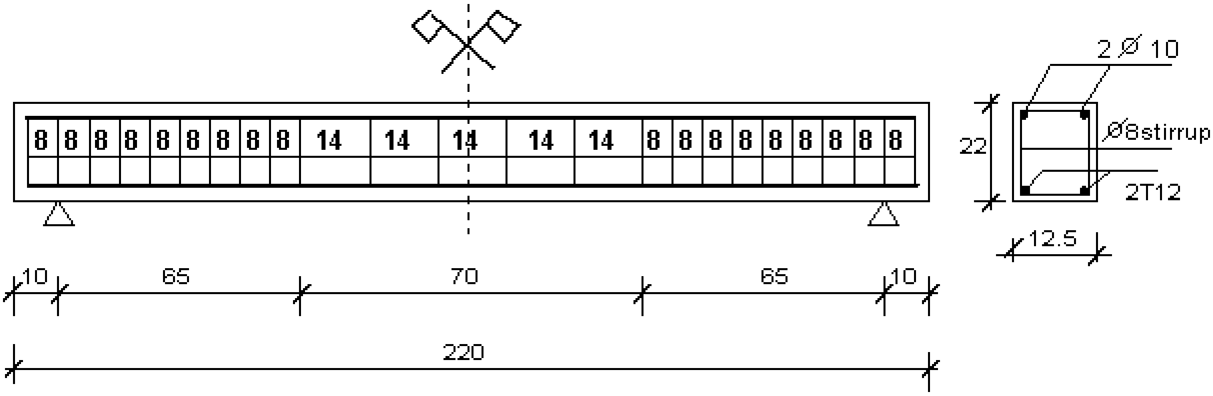

Figure 6: Reinforced Beam Tested in Bending

The experimental figured results characterising the test are regrouped in the table 2 hereafter.

Table 2: Figured Results

P_{ult} (KN)	M_{ult} (KN.m)	Deflection at appearance of the first crack (mm)	P_f (KN)	M_f (KN.m)	ε_a (‰)	ε_b (‰)
52	16.90	11.60	22	7.15	1.54	0.75

P_{ult}: The ultimate load, M_{ult}: The ultimate bending moment, P_f: The first crack load, M_f: The corresponding moment, ε_a and ε_b: The relative deformation of steel and sandcrete respectively.

Some comments could be made about the ultimate load and bending moment, the maximal deflection and also about the relative deformations of both steel and sandcrete:

- For the adopted beam cross sectional area (12.5 cm x 22 cm), the theoretical load and bending moment calculated by using the article A.4.3.41 of the French standard BAEL* 83 (in force in Algeria) were be 43 KN and 14 KN.m respectively. These results are lower of about 20% in comparison with the experimental ones. The theoretical values have been obtained with formulas conceived for usual concretes; they are then widely safe for this kind of non conventional concretes.
- The deflection evolution (figure 5) is approximately proportional to the applied load. For a simply supported reinforced usual concrete beam, the maximum deflection generally permissible depends on its length (len) and is worth len/500 (Renaud 1978). This, in case of crackless. If a such restriction is applied to the studied beam, the maximum deflection must be 4.40 mm. This limitation is far from the experimental measured value 11.60 mm. It can be then concluded that, from this point of view, the sandcrete material offers the safety required for the usual concrete.

* Béton Armé aux Etats Limites

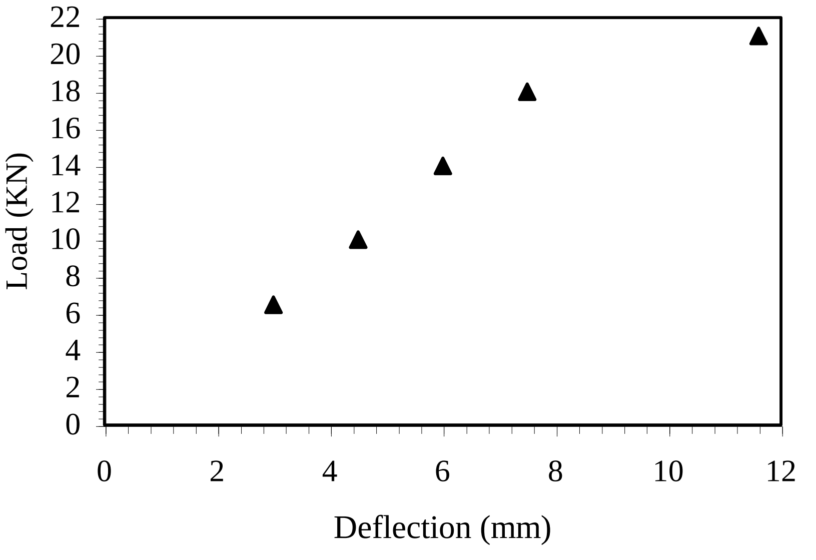

Figure 7: Deflection Evolution

- The figures 7 and 8 show respectively the sandcrete shortening in the most compressed area and the steel elongation in the tightest area. The sandcrete has reached at appearance of the first crack a relative deformation of 0.75 ‰, at this moment the steel is only in its elastic phase (ε_a = 1.54 ‰) according to the figure 7.

The brutal failure of the tested beam is to be noted, it suggests the brittle behaviour of the elaborated sandcrete.

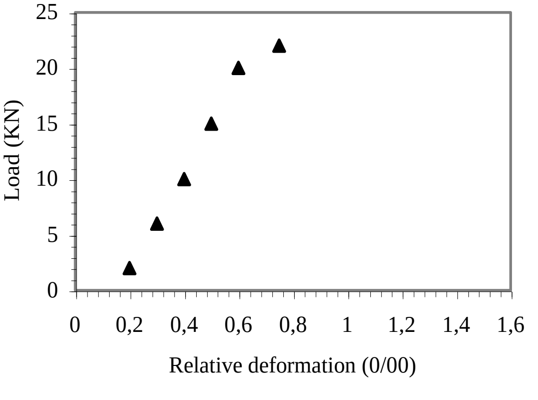

Figure 8: Sandcrete Shortening

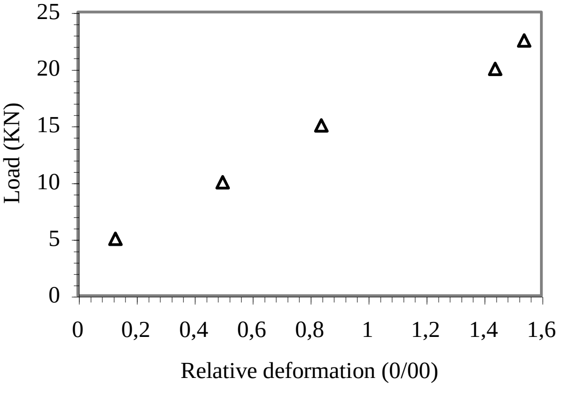

Figure 9: Steel Elongation

4-4 Crack pattern

An important aspect of the reinforced concrete behaviour lies on the disposition of cracks. The figure 8 hereafter shows the morphology of cracks appeared on the tested beam. The first cracks have appeared in the central area and were vertical. This proves that the sandcrete resistance has stopped and the steel has taken over from it. When increasing the load, inclined cracks have appeared outside the central area. They have continued to be open until the brutal failure in the zone of applied load.

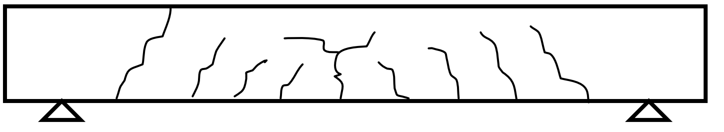

Figure 10: Crack Pattern

CONCLUSION

The dune sand could be a substitute material to form a skeleton of an interesting concrete. Its intrinsic characteristics give it the possibility, when a filler having preferably a calcareous nature, is inserted to correct its natural granularity and to make it denser.

The material sandcrete adheres well to building construction steels; the mean bonding stress obtained is situated in a very good position into the range of the usual concretes. The sandcrete can then be reinforced.

The behaviour of the sandcrete studied on the life-size beam allowed to note that it is similar to the usual concrete, the prescriptions of the BAEL 83 standard remains globally secure. It would be interesting to appreciate the effect of the behaviour parameters in an appropriate study.

The failure of the tested beam was brutal, it happened in the elastic phase. It proves the brittle behaviour of the sandcrete.

Two achievements can be made using this sandcrete:

- Secondary elements of buildings with a nice surface sight and architectonic effects,
- Structural elements for buildings slightly prompted witch can be those of modern housing with a few or no stories.

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