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Physic-Mechanical Characterizations of Sand Concrete: Paving of Road

El Hadji Lèye GUEYE[1] , Karim LIMAM[2] , Egle CONFORTO[2] ; Fatima Ezzahra LAFQIR[3,4] , Séni TAMBA[1], Lamine DRAME[5], Mba Beaugrain DOUMONGUE[2]

[1]Laboratory for Water and Environmental Sciences and Technology, Polytechnic School of Thies, Thies, Senegal
[2]Laboratory of Engineering Sciences for Environment, University of La Rochelle, France
[3]Equipe de recherche Procédés Energétiques, LMFE (URAC27), Faculté des Sciences Semlalia, Université Cadi Ayyad Marrakech, Maroc.
[4]Laboratoire EnR2E, Centre d'Études et de Recherches sur l'Eau et l'Énergie (CNEREE), Université Cadi Ayyad, Marrakech, Maroc.
[5]Lamine DRAME, statisticien manager of ERTCL_lab.
Email: elhadjigueye2020@gmail.com
Dakar, SENEGAL

Abstract The use of sand concrete makes it possible to produce a concrete with physic-mechanical properties that meets the criteria for use in self-locking paving block urban roads and has economic and environmental advantages over traditional concrete. There are several types of concrete formulations, but the study presented used the Dreux-Gorisse formulation and that based on an empirical formula of Caquot. They show, on the one hand, the mechanical tensile performance of sand concrete paving block at 28 days compared to traditional concrete and, on the other hand, large-scale use of sand concrete, which is more economical and more ecological in the construction of pavement urban roads. Still in the characterization of the sand concrete at the level of the production of the self-locking-paving-block, a microscopic analysis was made on the materials used with the environmental scanning electron microscope to determine their chemical composition.

Keywords Sand concrete, traditional concrete, properties physic-mechanical and chemical, environmental scanning electron microscope, self-locking paving block, pavement

Introduction

Environmental Issues [1], socio-economic and sustainable development in the field of public works are increasingly being taken into account by public authorities and industrial actors in all developed and developing countries. Concrete is now the most widely used building material in the world. Its success lies in its good mechanical properties, its durability, its geometric adaptability, its relatively good fire resistance and it is generally available and cheap [2].

The construction of buildings, bridges and road infrastructure requires significant quantities of quality materials. But beyond the quality of materials, governments are looking for local and sustainable alternatives to preserve the country's environmental quality. Whether they are public works sector or roads, the characteristics of the materials used must meet certain minimum quality requirements. In the case of construction or roads several categories of materials can be used. However, for the sake of economy, engineers are obliged to take account of the transport distances and the means operating the deposits.

At present, more and more criticisms are being made of it because of the environmental impacts generated by the production of cement, its main component. It should be noted that globally, 5% of total CO_2 emissions are from cement industries, which also consume 2% of total primary energy [3]. As cement is obtained by calcination at very high temperature (around 1450°C) of limestone and clay rock compounds. This is a process that requires a high energy consumption (coal, natural gas, oil, etc.) and generates very high CO_2 emissions. The CO_2 emitted by the means of transport and the generation of electricity necessary for the operation of cement plants must be added. According to a study published in June 2009 by [4], the global average quantity of CO_2 emitted per tonne of clinker produced in 2006 was 866 kg CO_2/t.

A country like Senegal needs to invest in a research and development program on sand concrete for the following reasons: developing its local resources; reduction in construction costs in the public works sector; scarcity of aggregates; abundance of raw materials (sand and fillerized sands) found in near inexhaustible quantities (Senegal is covered with more than 70% sand on the one hand and on the other hand, the fillerized sands which are co-products of the crushing of surplus massive rocks in quarries.

Then, the numerous research works synthesized in [5] [6] [7] [8] and [9] showed that the mechanical performance of lightweight aggregate concrete could be sufficient to be used as structural concrete. In this work we are interested in the exploitation of local materials in construction instead of using materials that require a very expensive supply, and as Senegal is very rich in sand of dune it was thought to exploit sand for the manufacture of sand concretes [10], [5], [11]. Sand concretes therefore have the same quantity of cement as traditional concretes (250 to 400 kg/m3); the compactness is reached by an additional addition of fine. Sometimes, certain uses of concrete require characteristics poorly assured by traditional concrete and that sand concrete can better satisfy, among these features we quote: The maneuverability, the cohesion and the absence of segregation, the small particle-size and the small size of the grains also the surface aspect and finally which is the most interesting its non-cracking character [4], which encourages us to use it as a repair material. The other interest in this material is the possibility of using industrial fillers to increase its compactness. To have a multi-purpose building material, denser with a very fine porosity, more impermeable and therefore more durable; silica smoke was introduced into the sand concrete formulation to see its effect on the sand concrete.

Indeed, the research and experiments carried out by the partners of the National Development Research Project "SABLOCRETE" [12] have shown that the technique of sand concrete pavements brings economic advantages, the preservation of natural resources and the environment in areas rich in sand.

In article [13] our initial contribution showed that it was quite possible to consider using sand concrete for construction purposes in the building sector.

This article is a continuation of previous work on sand cement. In order to optimise and offer large-scale sand concrete in the construction of urban paving roads, this experimental work concerns both the study of the characteristics of the materials constituting the sand concrete, then formulations used in the manufacture of fresh and hardened concrete, and finally comparative studies between the sand concrete and the traditional concrete on mechanical tensile strength and costs.

A large-scale application should also be made on a demonstration street in order to confirm with the Senegalese authorities the possibility of using the sand concrete in the construction of pavement urban roads.

The following paragraph shows the experimental approach that has ensured a good adequaty with the manufacturing requirements of self-locking paving block.

Methodologies

An experimental procedure can to permit to analyse chemical characterization with an instrument (figure 1).

The scanning electron microscope (SEM) used in this work is an Environmental FEI Quanta 200 – ESEM/FEG working at 20 KV, with the pressure of water vapor in the specimen chamber varying between 1.2 and 1.4 mbar. This environment is necessary in order to keep the residual humidity of some samples, like in concrete, without any preparation. Other dry, non-conductive materials as sand were also observed without any metallic coverage thanks to the surface charges neutralization provided by ionized water molecules surrounding the sample surface during analyses. Secondary electron-type images (SE), providing topographical information from the surfaces, were obtained in environmental mode using a "Gaseous Large-Field (LFD)" detector. Backscattered electrons (BSE), providing a chemical contrast from the surface, were simultaneously detected from the same zones as secondary ones, using a semi-conductor (SSD) detector. The methodology analyses are described in [15].

The SEM is equipped with an elemental chemical analysis system (Energy Dispersive Spectroscopy: EDS) EDAX GENESIS, able to identify the chemical el*ements locally present at the surface of the sample. This technique, based on the detection of* characteristics x-rays emitted by surface atoms during de-excitation after bombardment by the primary electron beam, is unable to detect the element hydrogen. The EDS analyses were standardless, semi-quantitative ones. However, a ZAF (Z: atomic number; A: absorbency; F: fluorescence) calculation is made on the intensity peaks of the raw spectra, in order to obtain the atomic (and weight) percent of each element in a ± 1% range. This calculation takes in account these three coefficients (Z, A, F) for each element detected in the spectrum in order to estimate its proportion respect to the others, and normalizing the ensemble to 100%.

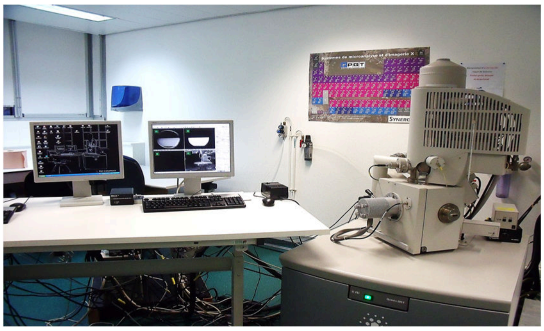
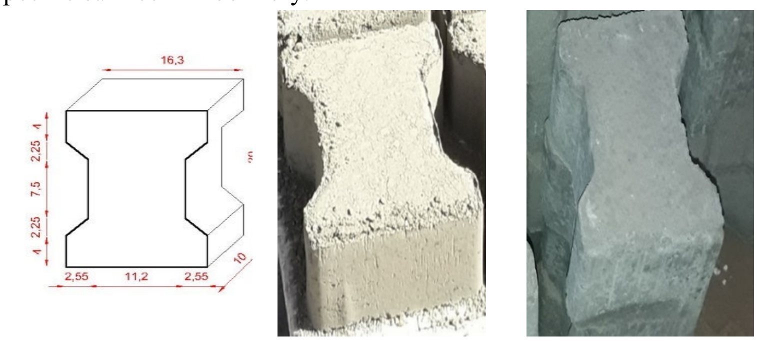


Figure 1: Environmental scanning electron microscope (CCA-LASIE)

We also identified other physical parameters such as sand equivalent at sight, sand equivalent to piston and specific surface in laboratory.



Dimensions of self-locking paving block | Traditional concrete | Sand concrete

Figure 2.a: Self-locking paving block (thickness of 10 cm) subjected to the direct splitting test

Figure 2.b: Press using for splitting tests

Finally, the composition of a paved concrete depends on the desired qualities. If the primary quality sought is mechanical tensile strength, a solid mixture with a minimum of empty, that is to say a high compactness and a small quantity of water should be sought. Once the paving block were prepared according to the two formulations defined above, we submitted the self-locking paving block to the test bench. After 28 days the paving block are crushed with a press (see Figure 2.b) to obtain the direct split tensile resistance of pavement.

The purpose of the tests is to determine the tensile strength of the concrete specimens in the shape of I (figure 2.a). They are immersed in water. Care should be taken to ensure that the test pieces to be tested (eight per test) do not have any asperities that could affect the quality of the test result. The test pieces are then dried and placed in the press while ensuring that the centering of the assembly is properly carried out. Finally, a breaking charge at the speed of 0,5 MPa/s is applied continuously and without shock along two opposite generators. If, it is referred to as P, the charge that causes the break by splitting into newtons, S the cross-section in mm², K_{10} the coefficient of correction of the thickness of the paving block, K_E the coefficient of calibration of the press, the resistance R to fracture by splitting in mega pascals, is given by the expression: $R = 0.637 \times K_{10} \times K_E \times \frac{P}{S}$

Figures 2.a and 2.b above show the geometry of the self-locking paving block that was sought in a press.

Important results on the physico-mechanical and chemical characteristics have been obtained in the following chapter.

Results and discussions

Following the physico-chemical characterizations of building materials we obtained the following results:

a. The physical properties of the materials used:

Table 1 shows that densities of different sands, found in this study are similar to that of a limestone silico aggregate because they are not only of the order of 2.65g/cm^3 but also the apparent density found are about 2 (two) times weaker than the real density.

Table 1: Physical properties of the materials used

Building Materials	Real density (g/cm^3)	Apparent density (g/cm^3)	Abs (%)	ES at sight (%)	ES to piston (%)	SS
Sand of dune	2.65	1.51	0.98	81	74	4390
Sand fillerized of basalt	2.99	1.50	1.96	-	-	1611
Cement	3.10	1.15	-	-	-	3000

- Abs: Absorptivity
- ES sight: Sand Equivalent at sight
- ES piston: Sand Equivalent to piston
- SS: Specific Surface

Table 1 also shows that the physical (intrinsic) characteristics of the materials used may vary depending on the types of rock encountered, their alteration or their degree of fracturing.

It also shows that absorptivity levels and specific surfaces are high which justify the importance of the amount of waste water compared to traditional concretes.

The specific surface of the cement found is correct. It must be between 2700 and 5500 cm^2/g, except for cement prompts (CPN) which are very fine (up to 7500cm^2/g).

Based on the values recommended for the sand equivalent by Dreux, the sand of dunes used are "clean sands", with a small percentage of fine clays perfectly suited for quality concretes.

Still in the physical characterization of the materials used, the results of the particle sizes are synthesized in the following paragraph.

b. Particle-size parameters:

The particle-size parameters are now presented in Table 2 below which gives the particle-size parameters that have been determined from an analysis to determine the respective size and weight percentages of the different families of grains constituting the sample. In fact, it applies to all aggregates of nominal size less than or equal to 90 mm, excluding fillers.

Table 2: Particle-size parameters

Particle-size parameters	% fillers (< 80µm)	Cu	Cc	So	Mf
Sand of dune	1.5	1.95	1.23	1.23	1.36
Sand fillérized of basalt	9.35	18	2.34	2.32	2.71

Table 2 shows that the natural sand of dune has a uniform size. The C_U coefficient is less than 3 (three). However with the sand fillerized of basalt used has a spread granulometry. Indeed, the Cu value above 3. It shows that sand fillerized basalt has a continuous granulometry (Cu >2) in addition is very well graduated (Cu ≥ 4 et 1< Cc < 3). It also shows that natural sand is finer than crushed sand because their Mf are weaker. A large amount of fines could pose problems in concrete because they have a high need for water which can lead to swelling and stiffening of the concrete.

Furthermore, in addition to the physico-mechanical characterization, a chemical characterization with the SEME (Environmental scanning electron microscope) was carried out to confirm the origin of the mother rocks used.

c. *Sand fillerized of basalt*:

With the SEME, the sand fillerized of basalt and the sand of dune are characterized in the following paragraph. The indications "light zone, dark zone" correspond to the contrasts observed in BSE images (electron images backscattered, which highlights the chemical contrast).

In order to explain or illustrate the mechanical and the chemical results of interest to us in this study, it is essential to characterize the basic constituents of sand concretes. These are mainly sand of dune naturel, sand fillerized basalt, Portland Cement CEM I 42.5 and water. The density and water absorption of the sands are measured in accordance with articles 8 and 9 of NF EN 1097-6. The results obtained are shown in Table 1 below

By performing an analysis on a surface of 725x600 microns on an agglomerate of particles we obtain a mineralogical composition containing heavy elements (Fe, Ti) and light (O, Si) (Figure 2 and 3) and Table 3.

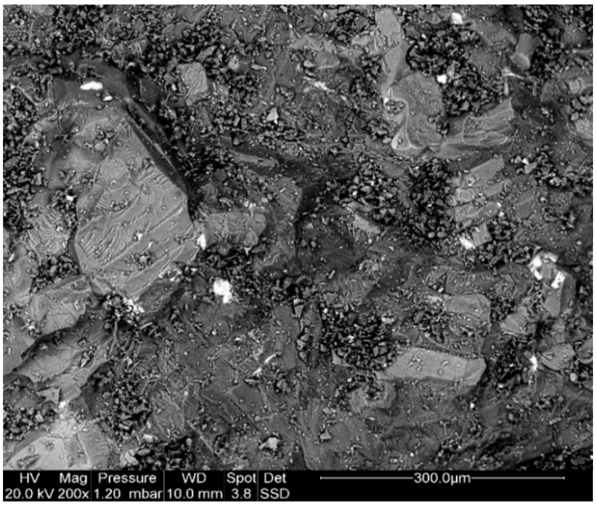


Figure 2 : *Microscopic image of a sample of sand fillerized of basalt on a 725x600 micron surface*

Elements	W%	At %
O	46,17	59.11
Na	0,7	0.11
Mg	2,28	3.24
Al	6,8	3.23
Si	22,02	12.53
K	1,17	0.60
Ca	11,68	11.20
Ti	1,08	1.40
Fe	8,09	8.57
TOTAL	100	100

Table 3 : Chemical constitution on a surface 725x600 microns sand fillerized of basalt

d. *Sand of dune*

By performing a spot analysis on the dark central zone (figure 4) in an agglomerate of particles, the silica predominates (Table 4 and figures 4 and 5).

The dark color indicates a mineralogical composition containing many more light elements (Si).

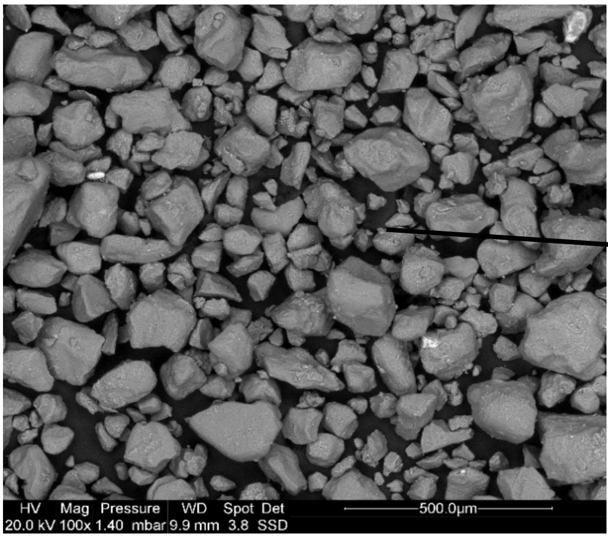


Figure 4 : Microscopic image of a sand of dune sample on a dark area in an agglomerate particles

Elements	W%	At %
O	47,89	63.63
Al	6,74	5.31
Si	36,23	27.42
K	0,75	0.41
Ti	0,64	0.28
Fe	7,75	2.95
TOTAL	100	100

Table 4 : Chemical constitution of sand of dune in dark zone

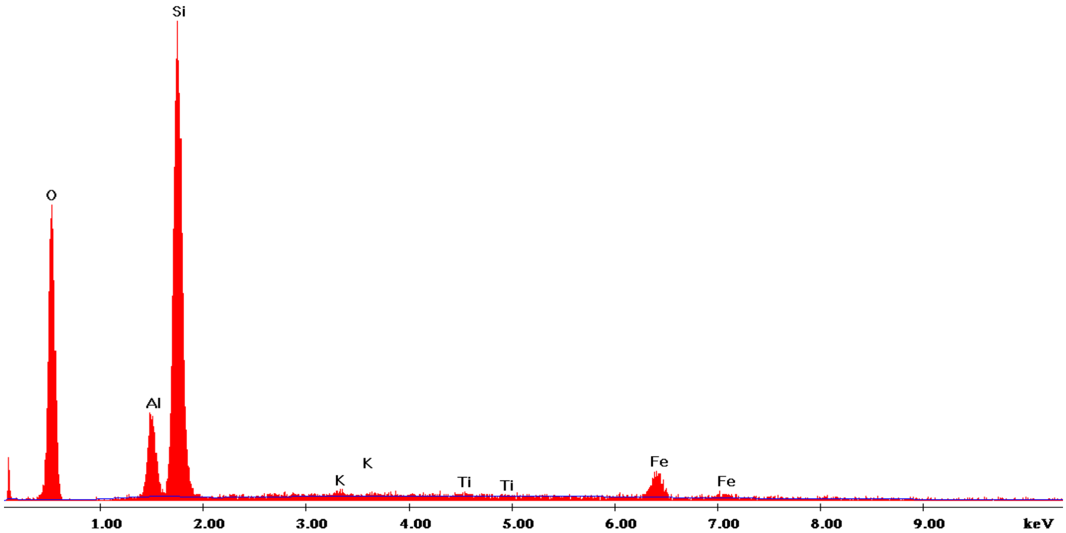
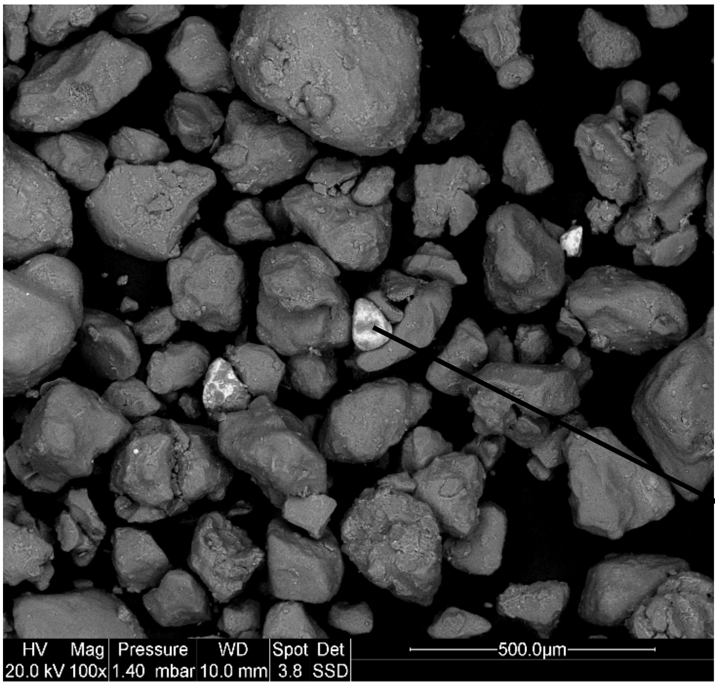


Figure 5: Spectrum 4, analysis on a dark zone in an agglomerate of sand of dune particles

By performing a spot analysis on the clear zone (figure 6) in an agglomerate of particles, Ti and Fe are present in the mineralogical composition (Table 5 and figure 7).
The light color indicates a mineralogical composition containing many more heavy elements (Ti, Fe).



Elements	W %	At %
O	41,87	63.15
Mg	0,33	0.33
Al	7,49	6.70
Si	14,83	12.75
K	0,81	0.50
Ti	22,29	11.23
Fe	12,37	5.35
TOTAL	100	100

Figure 6: Microscopic image of a sand of dune sample on a clear zone in an agglomerate of particles

Table 5: Chemical constitution of sand of dune in clear zone

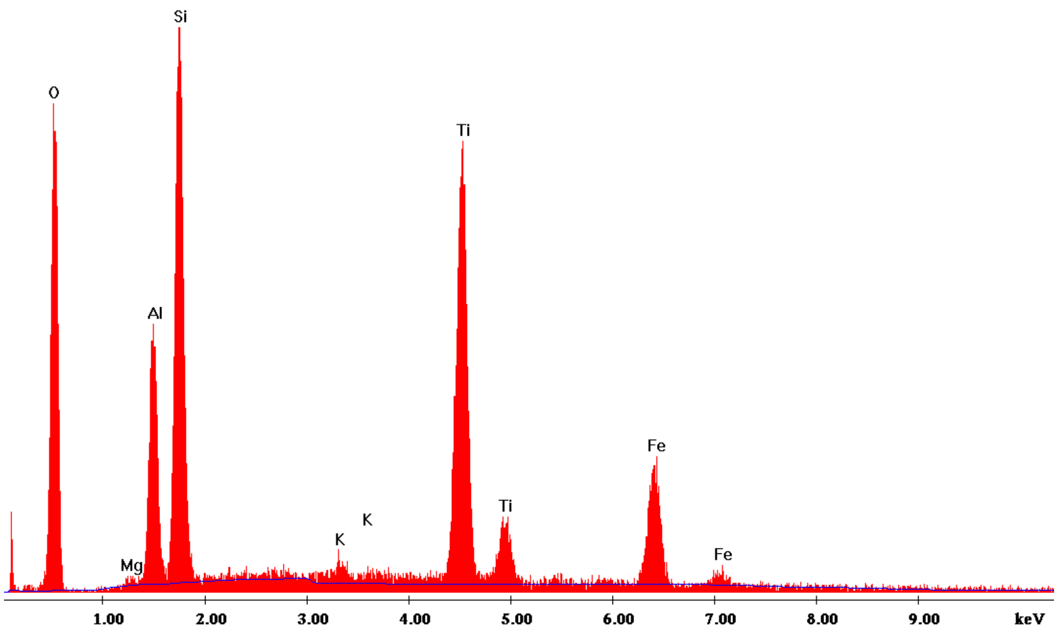


Figure 7: Spectrum 5, analysis on a clear zone in an agglomerate of sand of dune particles

In summary, the results found on the SEME with the sand fillerized of basalt made it possible to confirm the magmatic origin of this building material because its chemical composition varies like a magma within rather narrow limits. Indeed, oxygen is the most abundant element in weight and volume, followed by silicon (Si). Then come aluminum (Al), iron (Fe), magnesium (Mg), calcium (Ca), sodium (Na), potassium (K), etc.

Then, with sand dune, it is essentially light elements with predominance of silicon, calcium, oxygen which confirms in part their sedimentary origin.
In the following paragraph two formulations of sand concrete are used to make measurements of mechanical tensile strength at 28 days.
As far as concrete is concerned, the major unavoidable step is the formulation of the product before the evaluation of the mechanical properties in the laboratory. This paragraph will detail the various crucial steps.

e. formulation with the empirical formula of Caquot

Step 1 : Calculation hypothesis

$$\begin{cases} fc28 = 300bar \\ C = 400kg/m^3 \\ r = \dfrac{F}{F+G} = 0.227 \\ \dfrac{E}{C} = 0.35 \end{cases}$$

Step 2 : Applications of empirical formula of Caquot

$$\begin{cases} C' = \dfrac{250 + fcj}{\sqrt[5]{D}} \\ r = \dfrac{C+F}{C+F+\sum_{1}^{n} Sgi} \quad avec C' - C = F \end{cases}$$

Step 3 : Resolution of an equation system with two unknowns

$$\begin{cases} f1Sg1 + f2Sg2 = 41.5 \\ Sg1 + Sg2 = 1500 \end{cases} F = f1Sg1 + f2Sg2$$

$$S1 = \frac{Sg1}{1-f1} \quad S2 = \frac{Sg2}{1-f2}$$

Step 4 : Determination of the composition

$$\begin{cases} C = 400kg/m^3 \\ S_1 = 570kg/m^3 \\ S_2 = 973{,}41kg/m^3 \\ E = 140kg/m^3 \end{cases}$$

f. formulation of Dreux-Gorisse

Step 1 : Estimation volume of cement

$$V_c = \frac{C}{\gamma cement} = 130 liters$$

Step 2 : Estimation of total volume

$$V_T = (1000 * compacity) = 758 liters$$

Step 3 : Estimation of sand, 0/3 basalt and water volumes

V_G total volume of aggregate

$V_G = V_T - V_C$ $V_G = 628$ Liters ; $V_s = V_G \times 0{,}2$; $V_g = V_G \times 0{,}8$ and $Vw = \dfrac{C}{2.1}$

In our study we make a vibration of the concrete.

Step 4 : Determination of the composition for 1m3

% cement = 14 % ; % sand of dune = 13 % ; % 0/3 basalt = 53 % and % water = 20 %.

These two formulations will then make it possible to carry out an experimental study, to determine mechanical tensile strenght by splitting at 28 days and to compare the performance of the sand concrete and the traditional concrete.

g. Comparative Results and Analyses in Paving block Manufacturing :

The results of the crushing tests for both concretes (sand concrete and traditional concrete) are shown in Figure 2.b. Throughout the results and analyses below, the RT (mechanical tensile strength) are expressed in MPa. The results of the mechanical tensile strenght are shown in Figures 3 and 4 below, which show by comparing practical values obtained in the confection of self-locking paving blocks. We note that both sand concrete formulations exhibit acceptable behaviour vis-a-vis traditional concrete and NF P 98170.

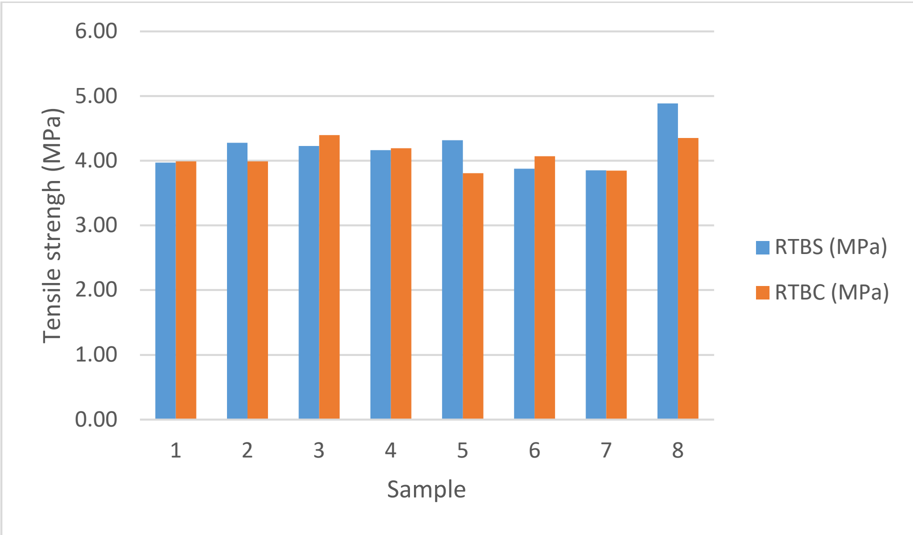


Figure 8: Comparison with the use of the Dreux-Gorisse (DG) formulation in the sand concrete

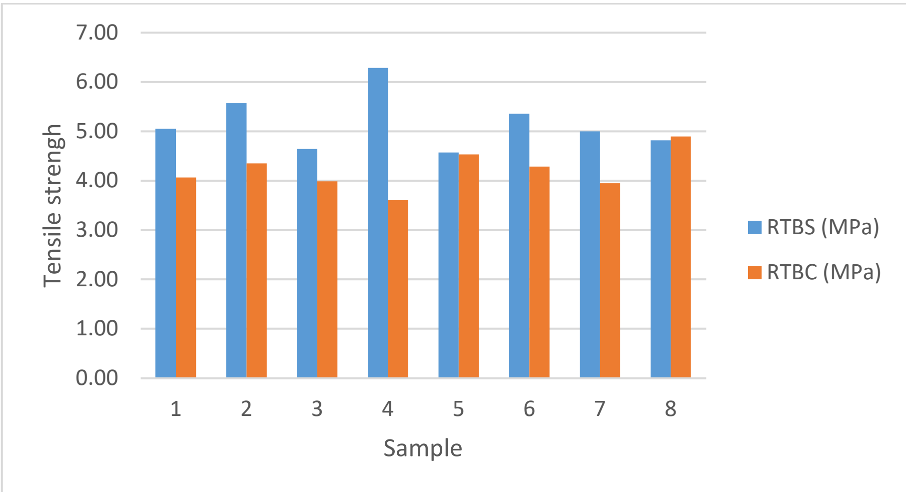


Figure 9: Comparison with the use of empirical formula of Caquot in the sand concrete

In short, when we refer to Figures (8 and 9) above, we can see that the sand concrete (BS) made by the Caquot method sometimes has values of resistance at 28 days higher than those of conventional concrete (BC) [14]. Indeed, taking into account the percentages of fillers in this formulation could be an advantage increasing the compactness because their role of filling empties. Furthermore, with the formulation of Dreux-Gorisse (DG), the tensile resistance by splitting of the two concretes (Figure 8) is almost the same.

h. Comparative results and analyses with the SEME between BS Caquot and BS DG:

The indications "light zone, dark zone" correspond to the contrasts observed in BSE images (electron images backscattered), which highlights the chemical contrast (figures 10a and b) below.

Table 6: Chemical constitution of the sand concrete Caquot on a surface of 1.4x1.2mm^2

Elements	W %	At %
O	45.53	53.74
Na	0.13	0.13
Mg	0.36	0.34
Al	1.62	1.37
Si	15.41	12.53
S	0.31	0.22
Cl	0.19	0.12
K	0.67	0.39
Ca	32.84	18.71
Fe	2.94	1.20
TOTAL	100	100

Table 7: Chemical constitution of sand concrete Dreux-Gorisse

Eléments	W%	At %
O	35.14	60.11
Na	0.29	0.34
Mg	0.54	0.61
Al	3.58	3.63
Si	7.10	6.92
S	0.20	0.17
Cl	0.22	0.17
K	0.89	0.62
Ca	6.18	4.22
Ti	8.88	5.07
Mn	0.77	0.38
Fe	36.22	17.75
TOTAL	100	100

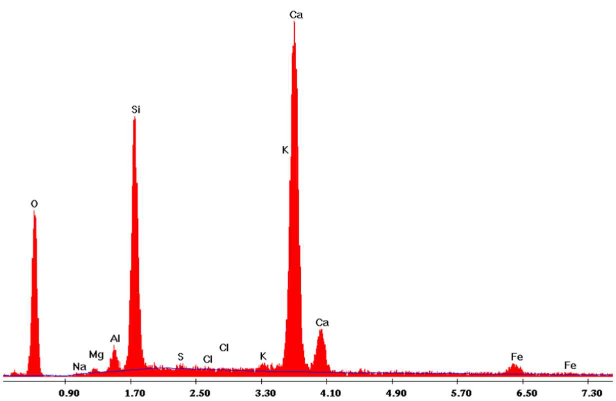


Figure 10a: Sand concrete spectrum with Caquot formulation

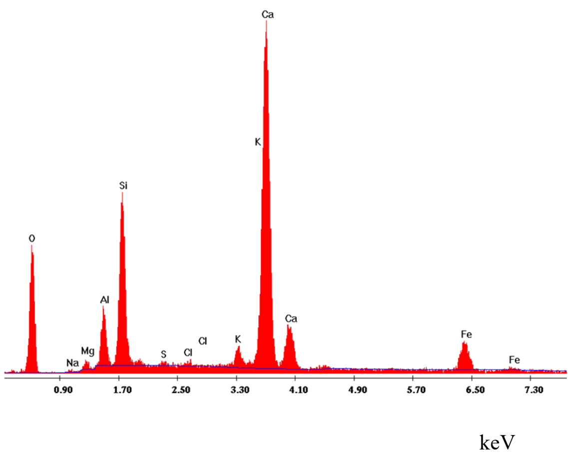


Figure 10b: Sand concrete spectrum with the Dreux-Gorisse formulation

Comments:

Finally with sand concrete following the two formulations (Dreux-Gorisse and Caquot) we have the same chemical elements. But the sand concrete following the formulation of Dreux-Gorisse is more porous, less compact (figure 10.a and 10.b the circles in red). This sometimes explains its insufficient resistance in some cases.

Therefore, the use of the Caquot method on sand concrete formulation would be more judicious as it offers very satisfactory resistances. Moreover, the choice will be clearer in the economic aspect.

i. Comparative economic

Table 8 summarizes below shows that sand concrete is more economical than conventional concrete with substantial gain regardless of the formulation method used.

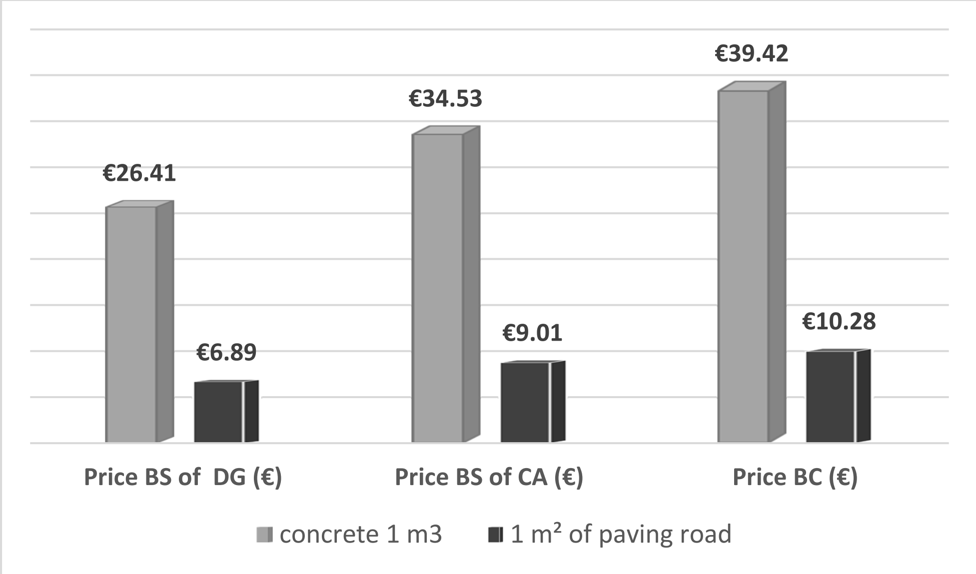
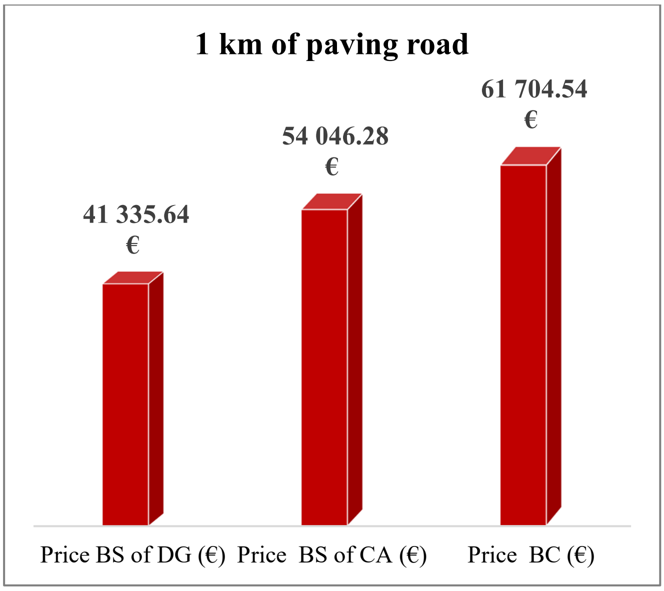


Figure 11.1 : Price of BS and BC according to the formulations of DG and CA



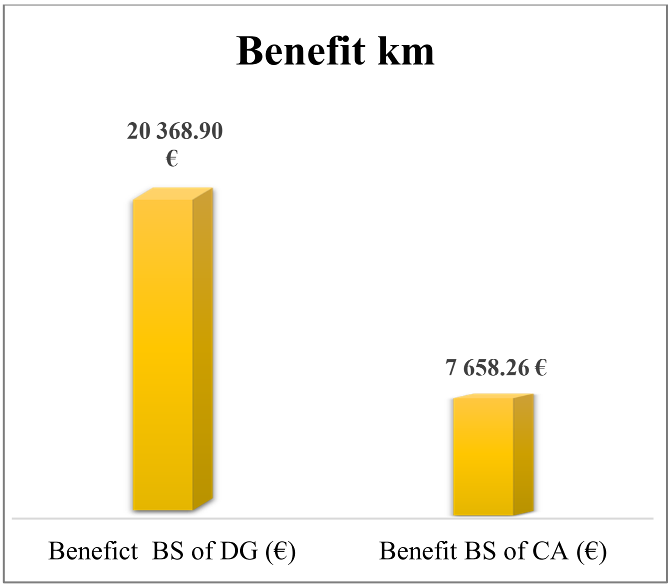


Figure 11.2: Benefits made on the bétons de sables following the formulation of DG and CA

In addition to this, the formulation of sand concrete by Dreux-GORISSE (DG), gives a very good price per m^3, however the tensiles strenghts are very lows. Therefore, with a strategy of development of urban roads (Figure 12) below in sand concrete pavement in order to optimize, the use of the Dreux-Gorisse formulation is better.

Figure 12: Photographs pavement of roads

Conclusion

The study of sand concrete that we have just conducted has shown that sand concrete paving can replace conventional concrete paving block while meeting the requirements for mechanical tensile strength.

The use of sand concrete can solve several problems and offer several advantages among which, the diversification in the choice of materials, which makes it possible to reduce the over-exploitation of mass rock quarries; the recovery of a waste in substitution of large caliber aggregates in public works; finally, the reduction of the cost of paving block, which will allow a better extension of the product in Senegal.

In view of the prospects, it would be interesting to direct the sand concrete towards urban roads in self-locking paving in view of the gains that are made in order to significantly reduce the costs of pavement roads and to improve the living environment of population, especially in flooded urban areas.

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