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Geotechnical analysis of the use of ferralitic laterites of Gonoum, Diendieme, Anisse and Assoumoul located in the regions of Ziguinchor and Sedhiou in south-west of Senegal as a pavement base course

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Abstract This article deals with the use of four ferralitic lateritic soils from the lateritic quarries of Gonoum, Diendieme, Anisse and Assoumoul located in the regions of Ziguinchor and Sédhiou in South-West of Senegal, as a pavement base course.

The results of this work have shown that the laterites studied are both compliant untreated and treated with an addition of 2% cement to the rules set by the catalog and dimensioning guide of AGEROUTE-Senegal of 2015 for their use respectively in base course of pavement with low traffic (NE < 107) and high traffic (NE > 107).

The results obtained also showed, for this percentage of addition of cement of 2%, that the values of simple compression strength (Rc and Rc') and indirect traction (Rit), remain in conformity with the rules of the AGEROUTE-Senegal for their uses in base course. From these analyses, a strong correlation was also noted between these strength parameters at 7 days (Rc, Rc' and Rit) for cement additions of 2%, 2.5% and 3%.

Keywords laterite, use, base course, treatment, cement, strength, simple compression, indirect traction

1. Introduction

The use of lateritic gravel in road construction in Senegal is dictated by the technical rules of the "catalog of new pavement structures and pavement dimensioning guide" of the Senegalese Agency for Road Works and Management (AGEROUTE-Senegal) of 2015 [1]. These rules are used to replace those used for decades defined by the "Experimental Center for Building and Public Works (CEBTP)" in 1984 [2]. When they do not meet these requirements, these materials are generally treated with cement to make them suitable.

The purpose of the work presented in this article is to study the possibility of using ferralitic soils from the lateritic quarries of Gonoum, Diendieme, Anisse and Assoumoul located in the regions of Ziguinchor and Sedhiou (South-West of Senegal) as a pavement base course without treatment for low traffic (NE < 10^7 load cycles) and with cement treatment for heavy traffic (NE > 10^7 load cycles).

The results of these studies are presented in the following.

2. Geotechnical properties of the studied laterites for use in pavement base courses

2.1. Location and geological characteristics of the samples studied

The studies carried out within the framework of this work were carried out on a laterite sample from the Gonoum quarry in the Zinguinchor region and on three samples from the Diendieme, Anisse and Assoumoul quarries in the Sedhiou region (Figure 1).

Figure 1: Origin of the lateritic samples studied

These samples are essentially ferralitic soils characteristic of these regions (Ziguinchor and Sedhiou) which are generally marked by a hot and humid climate [3].

The geological map of Senegal (Figure 2) also shows that these lateritic soils date from the tertiary era and are generally formed on clayey sandstone and marlstone.

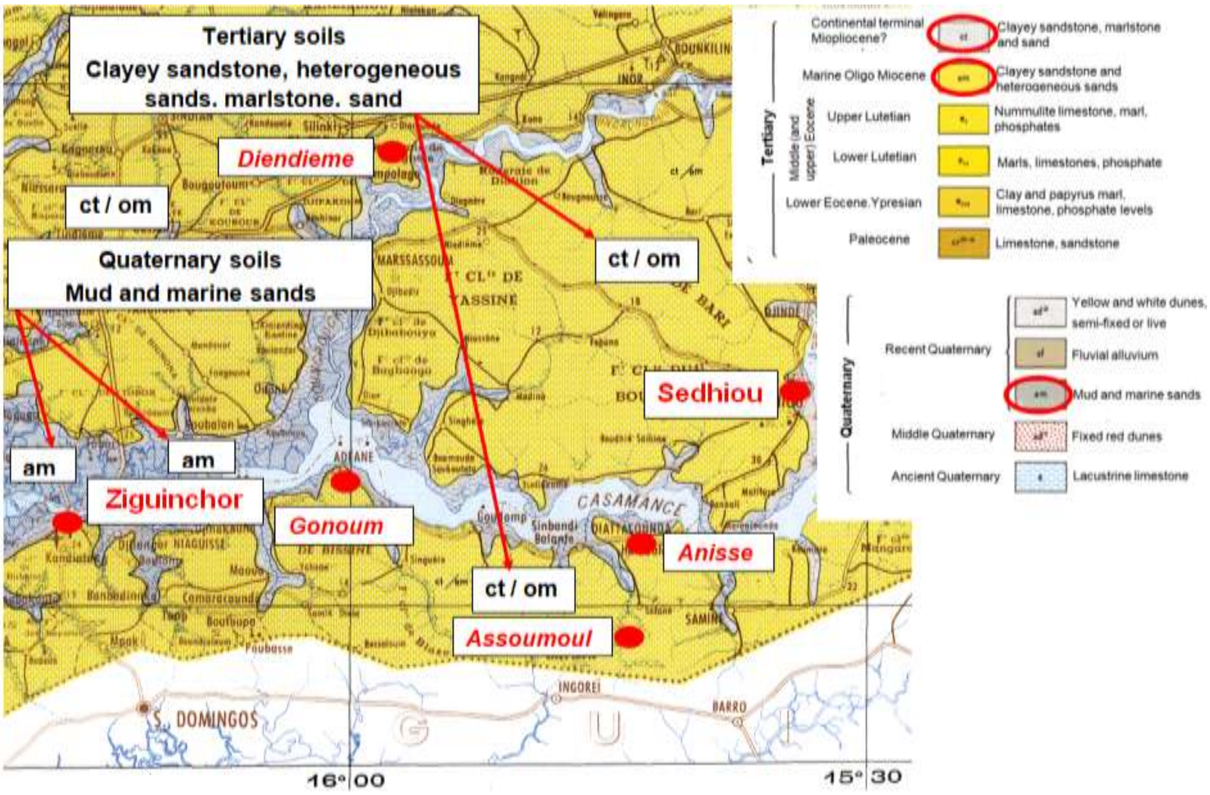

Figure 2: Overview of the geological formations present in the regions of Ziguinchor and Sedhiou (extract from the geological map of Senegal established by BRGM in 1962 [4])

2.2. Geotechnical properties

The selection criteria for lateritic materials to be used in pavement base courses are based on the specifications of the 2015 catalog of new pavement structures and pavement dimensioning guide of the Senegalese Agency for Road Works and Management (AGEROUTE-Senegal). The selection criteria for these materials are:

- the grading (standard NF P 94-056 [5]);
- the value of the plasticity index (I_P) (standard NF P 94-051 [6]) and
- the values of the Proctor compaction characteristics (w_{OPM}, ρ_{dOPM}) (standard NF P 94-093 [7]) and CBR (I_{CBR}) (standard NF P 94-078 [8]).

Figure 3 shows that the grading curves of the lateritic gravels studied are within the normative range of the AGEROUTE-Senegal guide.

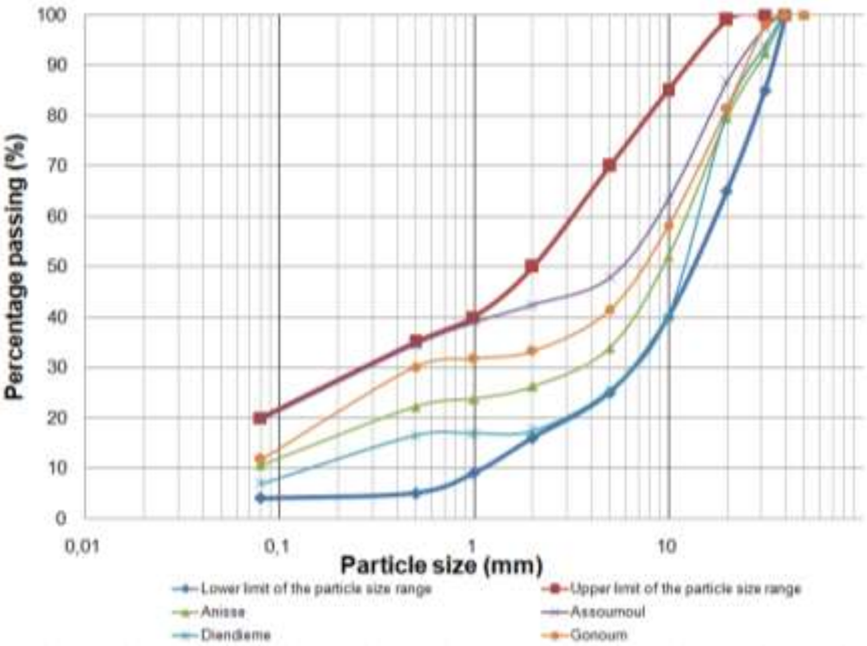

Figure 3: Representation of the grading curves of the lateritic gravels studied in the grading range recommended by the AGEROUTE-Senegal guide for use in pavement base courses

Table 1 also shows the conformity to the requirements fixed by AGEROUTE-Senegal [1] for use in base courses of the plasticity index (I_P) and compaction characteristics (w_{OPM}, ρ_{dOPM} and I_{CBR}) of the natural untreated lateritic gravels studied in the regions of Ziguinchor and Sedhiou (south-west of Senegal). All samples comply with the specifications set by the 2015 AGEROUTE-Senegal guide for plasticity index and modified Proctor compaction.

Table 1: Compliance of the plasticity and compaction index characteristics of the natural lateritic gravels studied with the requirements set by AGEROUTE-Senegal [1] for the base course

Location	Characteristics of the natural lateritic gravels studied	Limits of Atterberg		Proctor test		I_{CBR} at 4 days of immersion (%)
		Liquidity limit (w_L)	Plasticity index (I_P)	w_{OPM} (%)	ρ_{dOPM} (g/cm^3)	
Ziguinchor region	Gonoum quarry	28.0	14.1	8.6	2.08	70
Sedhiou region	Diendieme quarry	19.9	8.2	10.0	2.11	78
	Anisse quarry	25.4	9.8	10.5	2.01	68
	Assoumoul quarry	28.6	14.8	10.8	2.0	64
Specifications of AGEROUTE-Senegal		-	< 15	-	> 2	- > 60% if low traffic (NE < 10^7) - > 80% if heavy traffic (NE > 10^7)

NE = number of vehicle tire loading cycles

All CBR index (I_{CBR}) values comply with the AGEROUTE-Senegal rules (I_{CBR}> 60%) for use in a low traffic pavement base course (NE < 10^7). But they do not conform to the conditions put for use in a heavy traffic base course (NE > 10^7) since they all have CBR index values (I_{CBR}) lower than 80% (I_{CBR}< 80%).
To make them suitable, a chemical treatment with cement was adopted for all the studied samples since they all respect the rules required by the guide of the AGEROUTE-Senegal for a treatment with cement, namely to have:

- a maximum diameter less than 50 mm (D_{max}< 50 mm) ;
- a plasticity index value lower than 25 (I_P< 25) and
- a CBR index value (I_{CBR}) larger than 60% (I_{CBR}> 60%).

The results are presented in the following section.

2.3. Results of cement treatment of studied lateritic gravels for their use in pavement base courses
2.3.1. Conformity criteria
The rules of conformity used within the framework of this work are those defined by the guide of AGEROUTE-Senegal [1]. To define the conformity criteria, this guide distinguishes according to the percentage of cement addition:

- laterites “improved” with cement (Gla) which contain only a small percentage of added cement of the order of 2 to 3% and whose behavior remains “flexible” and
- cement-treated laterites (GLc) which contain a higher percentage of cement (around 4 to 6%) and whose associated behavior is said to be “semi-rigid” despite their low moduli of rigidity.

Thus, according to the percentage of cement addition, the criteria of conformity retained by the guide of the AGEROUTE-Senegal are defined below:

- for laterites “improved” with cement (Gla)
  - a modulus less than or equal to 2000 MPa (E ≤ 2000 MPa) (beyond that, the behavior of GLa would approach that of GLc);
  - a CBR value at 95% of the OPM after 3 days of cure in air and 4 days of soaking in water higher than 80% ($I_{CBR,\ 3\ days\ of\ cure\ in\ air\ +\ 4\ days\ of\ soaking}$ > 80%).
- For laterites “treated” with cement (GLc), the following criteria, similar to those proposed by the “Experimental Center for Building and Public Works (CEBTP)”of 1984 [2], are added to those defined for laterites “improved” with cement (Gla):
  - a workability time (standard NF EN 13286-45 [9]) higher than 2 hours at the time of implementation;
  - a dry density value at the modified Proctor optimum after treatment higher than 2 ($\rho_{dOPM\ after\ treatment}$> 2);
  - a value of immediate bearing index (I_{PI}) (standard NF EN 13286-47 [10]) higher than 50 (I_{PI}> 50%);
  - a CBR index value at 95% of the OPM higher than 60% (I_{CBR}> 60%) before treatment and a CBR index value at 95% of the OPM after 3 days of curing in air and 4 days of soaking in water higher than 160% ($I_{CBR,\ 3\ days\ of\ curing\ in\ air\ +\ 4\ days\ of\ soaking}$> 160%);
  - a simple compressive strength value (NF EN 13286-41 standard [11]) after 7 days of curing in air between 1.8 and 3MPa (1.8 <R_c< 3MPa);
  - a simple compressive strength value after 3 days of air curing and 4 days of soaking in water greater than 0.5 MPa (R_c’> 0.5MPa) and
  - an indirect tensile strength value (standard NF EN 13286-42 [12]) after 7 days of curing in air greater than 0.3 MPa (R_{it}> 0.3MPa).

These rules given by the 2015 AGEROUTE-Senegal guide [1] will be used to verify the compliance of the studied lateritic gravels.

2.3.2. Conformity of the results obtained on cement-treated lateritic gravels of Ziguinchor and Sedhiou studied

The studies of cement treatment were made by addition of cement CEM II/B-LL (or M) 32.5 R (standard NF EN 197-1 [13]) of the "Commercial Cement Company (SOCOCIM-Industries)". Within the framework of these studies, addition of 2%, 2.5% and 3% of cement was tested on each of the four samples studied.

Figure 4 summarizes the results of the influence of these additions of cement on the performance (CBR index) of the materials studied.

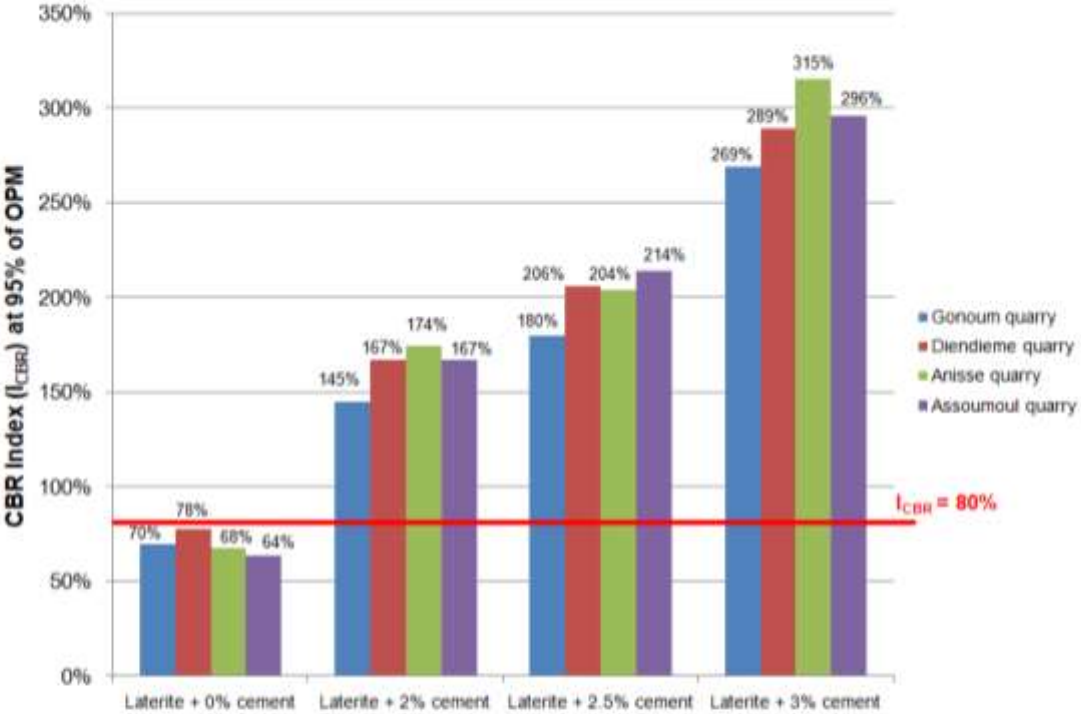

Figure 4: Evolution of CBR index (I_{CBR}) values by addition of 0%, 2%, 2.5% and 3% cement to lateritic gravels from Ziguinchor and Sedhiou

This figure shows that, for an addition of 2% cement, all the samples studied in the framework of this work largely exceed the value of the CBR index (I_{CBR}) of 80% (I_{CBR}> 80%) recommended by the rules of AGEROUTE-Senegal.

As a consequence, in accordance with the rules presented in section 2.3.1 of this paper, all the studied samples will be considered as "cement improved" lateritic gravels (Gla) with 2% of cement addition.

The moduli obtained after addition of 2%, 2.5% and 3% of cement are shown in Figure 5 and compared to the limit value for "cement improved" lateritic gravels (Gla) ($E \leq 2000$ MPa) in accordance with the rules set by AGEROUTE-Senegal [1].

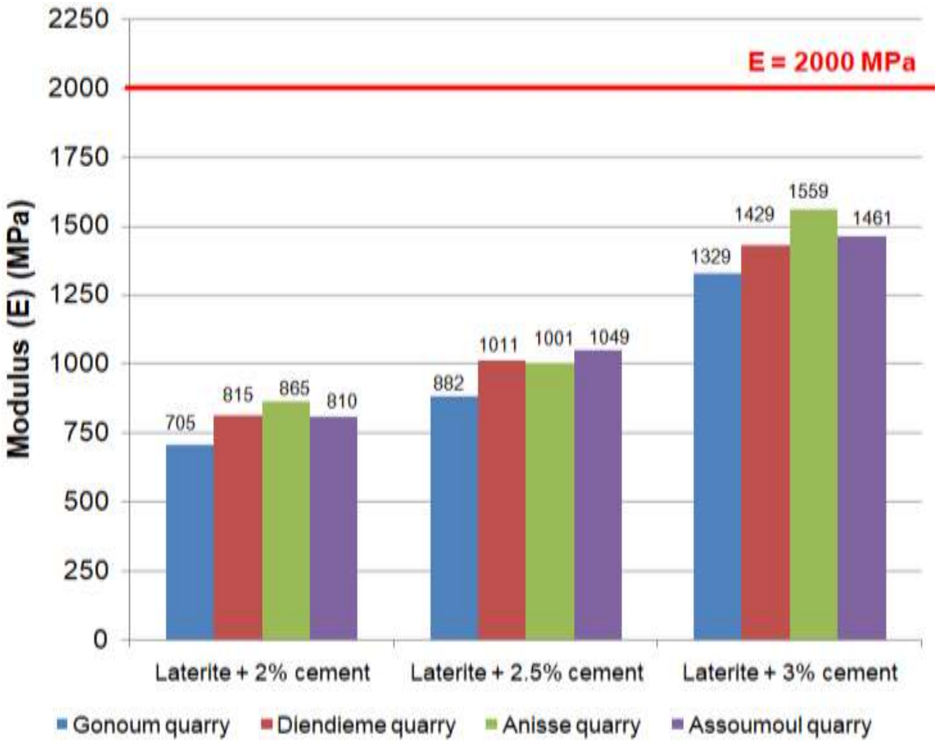

Figure 5: Moduli of lateritic gravels from Ziguinchor and Sedhiou after addition of 2%, 2.5% and 3% of cement

These moduli largely exceed the minimum value of 400 MPa fixed by the AGEROUTE-Senegal guide for the dimensioning of pavement structures with a base layer made of cement-improved lateritic gravel (Gla). Such studies should be continued on a Senegalese scale in order to better define the modulus minimum value of cement-treated laterite base courses (Table 2).

Table 2: Rules set by the AGEROUTE-Senegal rules for the design of pavement structures in GL1, GL2, Glli and Gla

Design parameters	**Nature of the materials**	
	GL1	**GL2 ou Glli ou Gla**
Modulus of the subgrade layer (E) (MPa)	- 2 times the modulus of the lower layer - Maximum value limited at 200 MPa	- 2 times the modulus of the lower layer - Maximum value limited at 400 MPa
Modulus of the base layer (E) (MPa)	200 MPa	400 MPa
Poisson's ratio (υ)	0.35	0.35

- GL1 : Untreated lateritic gravel of class 1
- GL2 : Untreated lateritic gravel of class 2
- Glli : Gravelly Laterite Lithostabilized
- Gla : Cement improved lateritic gravel

In practice, in addition to these verifications of conformity of the CBR index after treatment ($I_{CBR,}$ 3 days of cure in the air + 4 days of imbibition > 80%) and of the modulus ($E \leq 2000$ MPa), the verifications of conformity of the compressive strength (R_c and R_c') and indirect tensile strength (R_{it}) at 7 days are also carried out in the current building sites of Senegal on lateritic gravels improved with cement (Gla).

Strength tests were carried out on all the samples studied with addition of 2%, 2.5% and 3% of cement. The results are presented in Tables 3a to 3c and compared to the specifications of AGEROUTE-Senegal.

Table 3a: Compressive strength measured after 7 days of curing in air (R_c)

Location	Origin of the natural lateritic gravels studied	Compressive strength (R_c) after 7 days of cure in air		
		Laterite + 2% cement	Laterite + 2.5% cement	Laterite + 3% cement
Ziguinchor region	Gonoum quarry	1.81	2.63	3.96
	Diendieme quarry	2.63	4.30	5.30
Sedhiou region	Anisse quarry	2.29	3.09	4.88
	Assoumoul quarry	2.09	2.75	3.88
Specifications of AGEROUTE-Senegal		$1.8 < R_c < 3$MPa		

Table 3b: Compressive strength after 3 days of curing in air and 4 days of soaking in water (R_c')

Location	Origin of the natural lateritic gravels studied	Simple compressive strength after 3 days air cure and 4 days immersion (R_c')		
		Laterite + 2% cement	Laterite + 2.5% cement	Laterite + 3% cement
Ziguinchor region	Gonoum quarry	0.92	1.46	2.00
	Diendieme quarry	1.29	1.92	2.46
Sedhiou region	Anisse quarry	1.54	2.21	3.13
	Assoumoul quarry	0.83	1.08	1.84
Specifications of AGEROUTE-Senegal		$R_c' > 0.5$MPa		

Table 3c: Indirect tensile strength after 7 days of curing in air (R_{it})

Location	Origin of the natural lateritic gravels studied	Indirect tensile strength (R_{it}) after 7 days of cure in air		
		Laterite + 2% cement	Laterite + 2.5% cement	Laterite + 3% cement
Ziguinchor region	Gonoum quarry	0.31	0.45	0.65
	Diendieme quarry	0.34	0.60	0.73
Sedhiou region	Anisse quarry	0.40	0.55	0.98
	Assoumoul quarry	0.35	0.45	0.70
Specifications of AGEROUTE-Senegal		$R_{it} > 0.3$MPa		

These results shows that the values obtained for R_c, R_c' and R_{it} are all in conformity with the specifications of AGEROUTE-Senegal for an addition of 2% cement to the lateritic gravels studied.

The values of compressive strength (R_c) after 7 days of cure in air become too high for percentages of cement higher than 2%.

A strong correlation is noted between the strength parameters at 7 days (R_c, R_c’ and R_{it}) for additions of 2%, 2.5% and 3% cement (Figure 6).

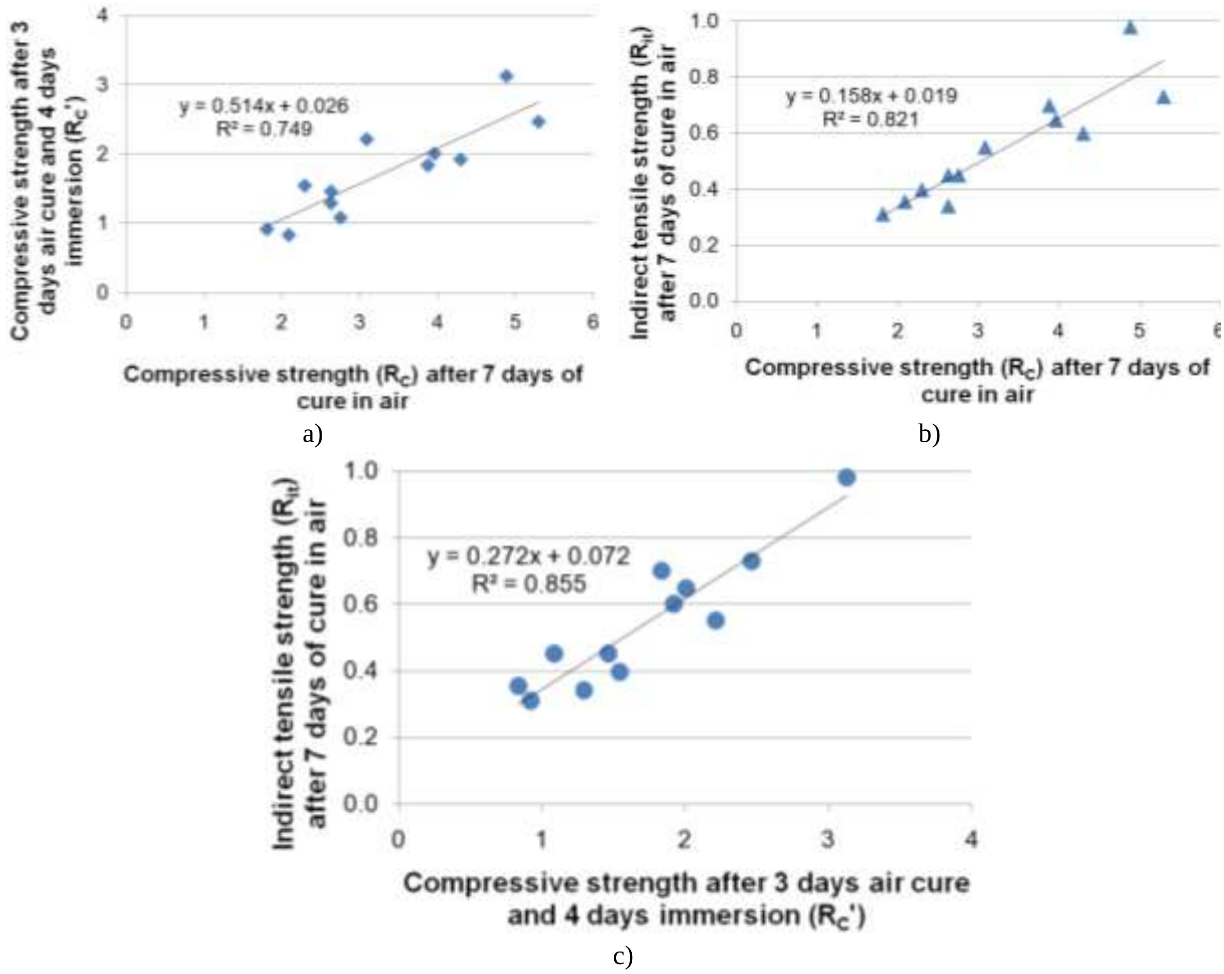

Figure 6: Relationships between the compressive strengths (R_c and R_c’) and indirect tensile strength (Rit) at 7 days of lateritic gravels with cement additions of 2%, 2.5% and 3%

From the graphs of Figure 6, the following relations were established:

$$R_c = 0.514*R_c' + 0.026 \quad \text{with } r = 0.865 \qquad (1)$$

$$R_c = 0.158*R_{it} - 0.019 \quad \text{with } r = 0.906 \qquad (2)$$

$$R_c' = 0.272*R_{it} + 0.072 \quad \text{with } r = 0.925 \qquad (3)$$

Similar analyses could be carried at the Senegalese level in order to identify more general trends.

3. Conclusions

The analyses carried out in this work have shown that the studied laterites from Gonoum, Diendieme, Anisse and Assoumoul quarries in the regions of Ziguinchor and Sedhiou (South-West of Senegal) comply with the rules of the 2015 AGEROUTE-Senegal catalog and design guide for use in their natural state without treatment as a pavement base course to support low traffic (NE < 10^7). For higher traffic (heavy traffic with NE > 10^7), the formulation studies of cement treatment showed that the addition of 2% of this binder made it possible to obtain modulus (E) and CBR index (I_{CBR}) results in accordance with the rules set by AGEROUTE-Senegal.

These experiments also showed that for a 2% addition of cement the materials studied can be classified as "gravelly lateritic improved with cement (Gla)" and that the obtained moduli (E) largely exceed the minimum value of 400 MPa fixed by the guide of the AGEROUTE-Senegal for the dimensioning of the structures of pavements with a base layer made up of materials of this class (Gla).

These findings have shown the interest to continue these studies at the Senegalese scale in order to better define the modulus minimum value of cement-improved laterite base courses (Gla).

For this Gla class, the analyses carried out on the verification of the simple compressive strength (R_c and R_c') and indirect tensile strength (R_{it}) values, for a 2% addition of cement, also made it possible to show that the lateritic gravel materials studied remain in conformity with the rules of AGEROUTE-Senegal for their uses in base course.

Besides, a strong correlation was noted between these strength parameters at 7 days (R_c, R_c' and R_{it}) for additions of 2%, 2.5% and 3% cement. Such analyses should be continued and extended to the Senegalese scale in order to confirm them and to identify more general trends.

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