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Activities and intrinsic properties of the clayey fines four lateritic gravels

Sorel Gael Dzaba Dzoualou [1], Louis Ahouet [1, 2, 3, *] and Sylvain Ndinga Okina [1, 2]

[1] *Department of Civil Engineering, Higher Institute of Architecture, Urbanism, Building and Public Works, Denis Sassou Nguesso University, Congo.*
[2] *Department of Civil Engineering, Higher National Polytechnic School (ENSP), Marien Ngouabi University – Brazzaville, Congo.*
[3] *Geotechnics Department, Control Office for Building and Public Works (BCBTP) – Brazzaville, BP 752, Congo.*

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Abstract

The aim of this study was to identify, classify and characterize the activities and correlations between the intrinsic properties of the four lateritic gravels used in construction. The grading curves of the four lateritic gravelly are spread out, but poorly calibrated. Lateritic gravel LG_1 contains class B_5 silty fines with low plasticity and low swelling. Lateritic gravels LG_2, LG_3 and LG_4 contain clayey fines of low plasticity and medium swelling, class B_6. The specific surface area and cation exchange capacity depend on the mineralogy, organic composition and texture of the lateritic gravel. The blue value of the soil characterizes the activity of the clay fines and reflects the surface activity of the lateritic gravels. The four lateritic gravels are inactive and contain minerals (kaolinite, quartz, goethite, hematite). The correlations obtained between the intrinsic properties are linear fits and between the liquidity limit and the specific surface area a non-linear fit of the ExpDec1 model with R^2 (0.99). The relationship between activity and surface activity is simply the relative activity.

Keywords: Activity; Specific Surface Area; Cation Exchange Capacity; Mineralogy; Atterberg Limit; CBR

1. Introduction

In sub-Saharan Africa, lateritic gravel is one of the most widely used local materials for road construction due to its abundance [1-6]. Lateritic gravel consists of pebbles covered with a thin layer of clay. Lateritic gravels have a low investment cost, unlike the exploitation phase, which has a high cost due to the early degradation of the material [7]. In rainy regions, dirt roads become sticky and slippery due to the high clay content of lateritic gravel, which degrades in no more than two years. During the dry season, dirt roads give off a lot of dust, reducing drivers' visibility and causing accidents. The behavior of lateritic gravel depends not only on its granularity, but also on its mineralogy. To reduce the costs and environmental impact of road construction and maintenance, the use of lateritic gravel can be an asset if it is preceded by the necessary geotechnical studies [8-10]. Although very varied, studies on lateritic gravels have not exhausted the subject. It will always be important to carry out the necessary tests for each lateritic gravel. The activity of clay fines in lateritic gravels has not yet been reported. The activity of lateritic gravels is defined by the ratio between the plasticity index and its clay fraction. This activity is linked to the mineralogy and geology of the clay fines, which are classified into three groups (inactive, normal and active) [11]. The involvement of the clay fraction in the definition of activity indicates the variation in the physic-chemical potential of lateritic gravels as a function of their plasticity index. The plasticity index is used to describe the quantity and type of fine clay contained in lateritic gravels. The plasticity index defines the range of water content over which a soil exhibits plastic behavior.

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[*] Corresponding author: Louis Ahouet

In other words, we would expect that for two lateritic gravels with the same clay fraction, the lateritic gravel with the more active mineral should have the higher plasticity index. Specific surface area and cation exchange capacity are two fundamental properties that dominate the behavior of clay fines in lateritic gravel. Cation exchange capacity and specific surface area, used in combination with the fraction of fine clay, can be used to define new activity values. However, relative activity defines the role played by the specific surface area of lateritic gravels on their plasticity [12]. In other words, two lateritic gravels with different clay fines contents and the same plasticity index can be expected to have different specific surface areas, depending on their mineralogy. However, the clay fraction of lateritic gravels does not identify the mineral species present. The specific surface combined with the clay fraction only gives an idea of the mineralogy. Of all the mineral constituents of lateritic gravels, clay fines contribute the largest surface area, which can vary considerably. Non-swelling soils such as kaolinites generally have specific surface areas between 10 and 40 m2/g [13] and 15 and 26 m^2/g [14]. However, the type of mineral in the clay fractions of lateritic gravels has played a major role in determining the effect of specific surface area on the properties of clay fines. Specific surface area depends on grain distribution and mineralogy. Specific surface area can be considered an inherent property of the clay fines in lateritic gravels. The specific surface and cation exchange capacity of lateritic gravels are considered intrinsic properties. Water content and time do not alter the fundamental properties of lateritic gravel. The swelling potential of lateritic gravel depends on the mineralogy of the clay fines. For a given clay fraction, the specific surface area and cation exchange capacity are proportional to the mineralogy in the order kaolinite - illite - montmorillonite [11]. The aim of this work was to identify, classify and characterize the activities of four lateritic gravels used in construction. On the basis of their geotechnical properties, to determine the activities, specific surface areas, cation exchange capacities and correlations between the intrinsic properties of lateritic gravels.

2. Material and methods

2.1. Material

Four samples of lateritic gravels were collected in four localities in the south-east of the Republic of Congo. The locations where the material was collected are shown in Table 1. At each collection site, approximately 150 kg of lateritic gravel was collected. The color of the laterite gravel varied from yellow to reddish. Lateritic gravel samples will be denoted by the letters GL followed by an index.

Table 1 Location and sampling of lateritic gravels.

Soil	Locality	Sample	Place of collection
Lateritic gravel LG	Kigouala	LG_1	S04°10’34.1’’; E013°28’40.4’’
	Miyambi	LG_2	S4°10’31.5’’; E012°47’38.7’’
	Tsiaki	LG_3	S04°10’19.5’’; E012°52’17.4’’
	Tsanga	LG_4	S4°08’26.3’’; E13°33’41.8’’

2.2. Methods

Samples taken in situ are transported to the laboratory for analysis. The analyses are carried out after sieving the lateritic gravel with a 40 mm sieve to obtain a 0/31.5 mm lateritic gravel. The geotechnical properties defined include grain size, Atterberg limits, methylene blue value, dry density (modified Proctor) and CBR index for soil characterization. On the basis of the geotechnical properties, the specific surface area, cation exchange capacity and activities of the four lateritic gravels were determined.

Grain distribution was determined by granulometric analysis based on two types of tests. These are granulometric analysis by sieving for grains of size $\phi > 80$ µm according to standard NF P94-056 [15] and sedimentation for grains of diameter $\phi \leq 80$ µm according to standard NF P94-057 [16]. Granulometry nomograms, considering fine clays as particles smaller than < 0.002 mm, silts 0.002-0.06 mm and sands 0.06-2 mm were used to determine the granulometric fractions of lateritic gravels. The coefficients of curvature Cc and uniformity Cu were used to characterize the grain size of the lateritic gravels, according to the following formulae:

$$C_U = \frac{D_{60}}{D_{10}} \ldots\ldots\ldots\ldots (1)$$

$$C_C = \frac{{D_{30}}^2}{D_{30*}D_{60}} \ldots\ldots\ldots(2)$$

Where Dx - is the grain size corresponding to x % by weight of sieves.

The Atterberg limits (liquidity limit, plasticity limit, plasticity index) were determined in accordance with standard NF P 94-051 [17]. The liquidity limit and the plasticity limit are determined on the fraction of soil passing through a sieve with an opening of 0.40 mm, obtained by the following relationship:

$$PI\ (\%) = L_L - P_L \ldots\ldots\ldots\ldots(3)$$

The classification of the four lateritic gravels soils makes it possible to create groups of soils with similar characteristics. This grouping makes it possible to identify lateritic gravels and, consequently, to get an idea of their mechanical behavior. This is made possible by quantitative measurements such as particle size analysis, Atterberg limits, water content, dry density, CBR, etc. Depending on the arrangement of the grains in the soil, a distinction can be made between uniformly graded and non-uniformly graded soils [18]. Depending on the physical and chemical properties of the grains, lateritic gravels are classified by the AASHTO T88-70 [19] and USCS [20] classification systems. The two classifications differ in the values of the parameters taken into account (grain size and Atterberg limits). The AASHTO soil classification system is used as a guide for classifying soils and soil-aggregate mixtures for road construction purposes.

The blue value of the soil is obtained on the 0/2 mm fraction and the value found is related to the 0/50 mm fraction using a proportionality rule. The blue value of the soil is a parameter used to characterize the clay content of a soil. The blue value of the soil is directly related to the specific surface area of the soil and is determined by the methylene blue staining test on a 0/2 mm fraction, in accordance with standard N FP 94-068 [21].

Determining the specific surface area is of great importance for phenomena involving surfaces, such as water adsorption and absorption. The surface area of a soil is considered to be an inherent property, controlled by the particle size distribution and mineralogy of the clay fines. Specific surface area can be determined by the formula:

$$SSA = 20.93*BVS \ldots\ldots\ldots (4)$$

Where SSA is expressed in (m^2/g) and BVS in (g/100g).

The cation exchange capacity corresponds to the quantity of cations in the double layer that can be easily replaced or exchanged by other cations per 100 grams of soil. It can be determined by the following formula:

$$CEC = \frac{BVS*1000}{374} \ldots\ldots\ldots\ldots (5)$$

With CEC expressed in (meq/100).

Specific surface area (SSA) and cation exchange capacity (CEC) are intrinsic properties that dominate the behavior of fine clays in lateritic gravels. The activity (Ac) characterizes the mineral contained in the fine clay particles, defined by the formula:

$$AC = \frac{PI}{CF(\%)<0.002\ mm} \ldots\ldots\ldots\ldots (6)$$

The relative activity is defined as the ratio between the plasticity index and the specific surface defined by the following formula [12]:

$$RA = \frac{PI}{SSA} \ldots\ldots\ldots\ldots (7)$$

The minerals (Kaolinite and Illite) can be defined according to the Sc surface activity expressed by the following formula:

$$Sc = \frac{SSA}{CF} \ldots\ldots\ldots (8)$$

with, Sc ($m^2/g*102$).

The minerals (Illite and Montmorillonite) are defined in terms of cation exchange capacity activity (CECA) by the following formula:

$$CECA = \frac{CEC}{CF} \text{..........(9)}$$

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3. Results

3.1. Geotechnical properties of study material

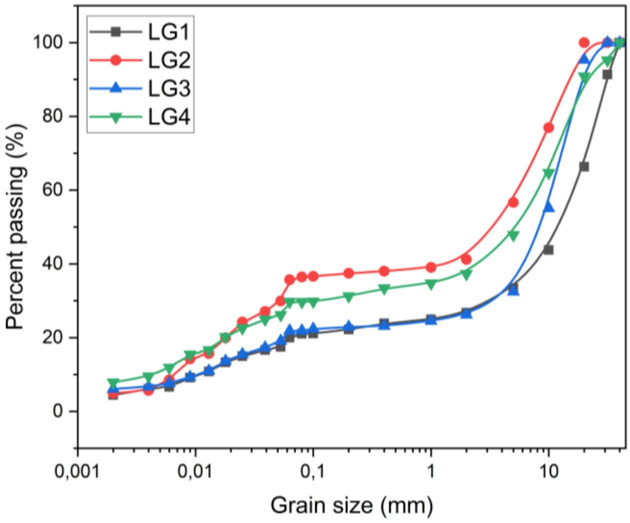


Figure 1 Size distribution of the four lateritic gravel deposits

Figure 1 shows the particle size distribution of the four lateritic gravels. The clay, silt, sand and gravel contents are shown in Table 1. The maximum diameter of large grains in the four lateritic gravels is 31.5 mm. The results obtained on the Atterberg limits and those extracted from the grading curves in Figure 1 are shown in Table 1.

Table 1 Identification of lateritic gravels (LG1, LG2, LG3, LG4)

Sample	Clay (%)	Silt (%)	Sand (%)	Pebbles (%)	BVS (g/100g)	CI	LL (%)	PL (%)	PI (%)
LG1	3.2	22.35	1.188	73.27	2.2	0.47	17.45	8.78	8.67
LG2	3.88	32.22	1.186	62.72	3.5	0.82	27.00	13.31	13.69
LG3	3.33	25.9	1.195	69.58	2.6	0.91	24.20	14.0	10.2
LG4	4.23	35.8	1.186	58.78	4.3	0.78	27.80	11.0	16.8

Particle size fractions (clay, silt, sand, gravel), BVS (%) - blue value of the soil, CI - consistency index, LL (%) - liquidity limit, PL (%) - plasticity limit, PI (%) - plasticity index.

Sample LG1 has a consistency index CI (0.47), i.e., the clay fraction of the lateritic gravel has a soft consistency. The lateritic gravels LG2, LG3 and LG4 have consistency index CI (0.78-0.91), i.e., the materials have a consistency in the range from semi-consistent CI (0.75) to consistent CI (1) and have natural water contents WC (13.20-16.20%). The blue value of the soil (BVS) reflects the overall quantity and quality (activity) of the clay fraction of the soil [18]. The blue values of the soil of lateritic gravels LG2, LG3 and LG4 are within the range (2.5 < BVS < 6) of soils with average plasticity. The lateritic gravelly LG1 has a BVS (2.2 g/100g) of less than (2.5 g/100g), i.e., the soil is a low plasticity silt [18]. The grain sizes corresponding to D10, D30 and D60 by weight of sieved material, deduced from the curves in Figure 1, are shown in Table 2.

Table 2 Determination of uniformity coefficients Cu and curvature coefficients Cc of grading curves for lateritic gravels (GL1, GL2, GL3, GL4)

Samples		Diameter		Coefficients	
	D10	D30	D60	Cu	Cc
LG1	0.01	3.16	16.33	3599.3	35991.01
LG2	0.01	0.05	5.43	807.11	231
LG3	0.01	1.76	10.78	913.96	2843.05
LG4	0.01	0.13	8.22	757.35	13.08

The lateritic gravels (LG1, LG2, LG3, LG4) have uniformity coefficients Cu > 4, i.e., the grading curves are spread out. In other words, the particle sizes of (LG1, LG1, LG2, LG3, LG4) are composed of clay, silt, sand and gravel (Table 2). In relation to the specifications [18], the four lateritic gravels are class B_5 (LG1) and B_6 (GL_2, GL_3, GL_4), like most of the lateritic gravels studied [2-4,7].

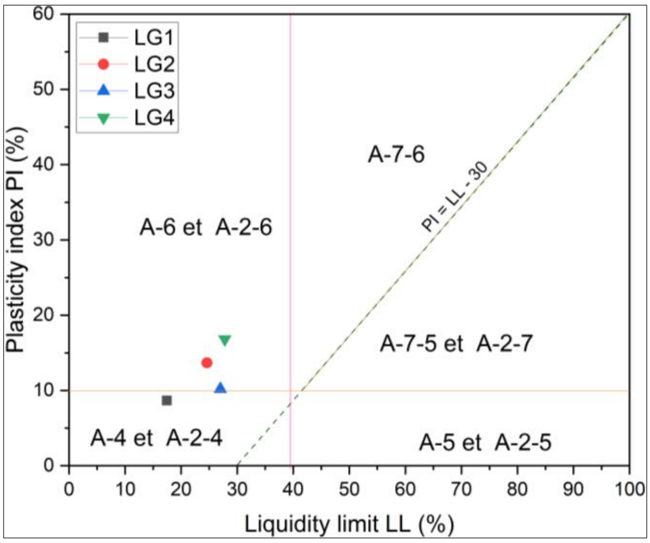


Figure 2 AASHTO classification of lateritic gravels

The results obtained show that the lateritic gravel LG1 is classified as silt according to the USCS classification, B_5 according to the classification GTR 92 [18] and A4 or A-2-4, according to the AASHTO T88-70 [19] classification. The lateritic gravels LG2, LG3 and LG4 are low plasticity clays according to the USCS classification, classified B_6 according to the GTR 92 [18] and A6 or A-2-6, according to the AASHTO T88-70 [19] classification. The results obtained are shown in Table 3.

Table 3 Classification of lateritic gravel (GL1, GL2, GL3, GL4)

Sample	Classification		
	GTR 92	USCS	AASHTO
LG1	B_5	Silt	A-4 et A-2-4
LG2	B_6	Clay	A-6 et A-2-6
LG3	B_6	Clay	A-6 et A-2-6
LG4	B_6	Clay	A-6 et A-2-6

Figure 3 shows the Casagrande plasticity chart, which defines the plasticity range of the four lateritic gravels.

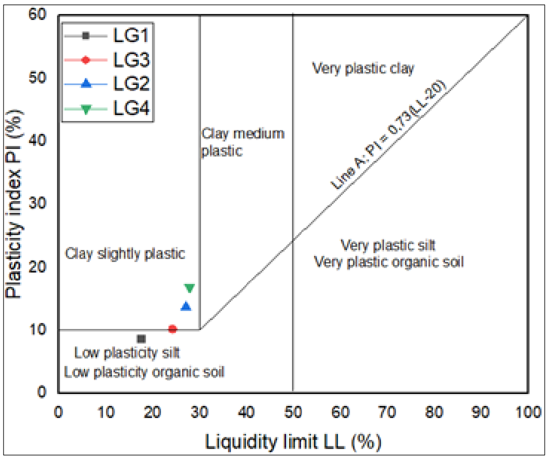


Figure 3 Plasticity of clay fines in lateritic gravels

In Figure 3, the fines of the lateritic gravels LG1, LG2 and LG3 belong to the weakly plastic clays group and GL4 belongs to the weakly plastic silts group. The lateritic gravel LG3 is at the limit of the weakly plastic clays and silts groups.

Table 4 Mechanical properties of lateritic gravels

Sample	**Fines (%)**	**OMC (%)**	**MDD T/m^3)**	**CBR (%)**	**E$_{st}$ (MPa)**
LG1	21	10.0	1.97	20	200
LG2	36	13.74	1.71	23	230
LG3	23	7.43	2.2	68	680
LG4	32	10.63	1.95	25	250

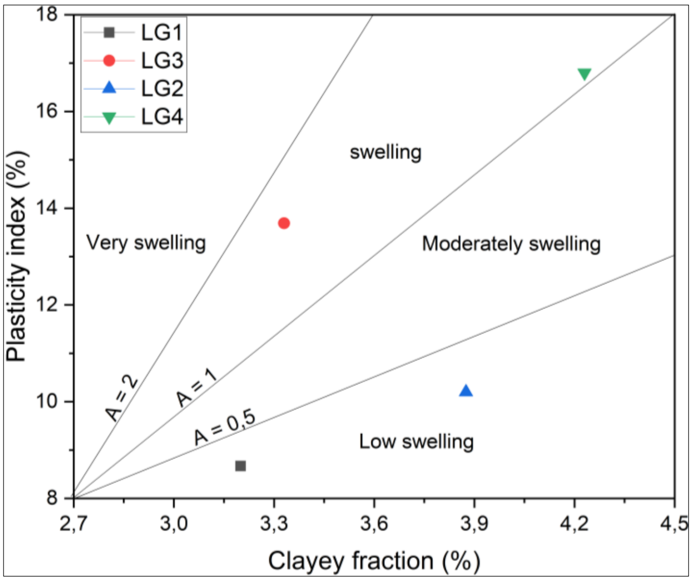


Figure 4 Swelling potential of lateritic gravels

The CEBTP 1984 [22] classification divides laterites into three groups (G/1, G/2, G/3) defined on the basis of geotechnical parameters (CBR, maximum dry density, optimum moisture content, plasticity index, % fines and static modulus). Sample LG1 has a percentage of fines of 21% (G/2), a water content of 10% (G/2), a CBR index of 20% (G/2), a dry density of 1.97 T/m^3 (G/3) and a static modulus of 200 MPa (G/1). Sample LG2 has a percentage of fines of 36%

(G/3), a water content of 13.74% (G/3), a CBR index to 23% (G/2), a dry density of 1.71 T/m^3 (G/3) and a static modulus of 230 MPa (G1). Sample LG3 has a percentage of fines of 23% (G/2), a water content of 7.43% (G/2), a CBR index equal to 68% (G/1), a dry density of 1.95 T/m^3 (G/3) and a static modulus of 680 MPa (G/3). Sample LG4 has a percentage of fines of 32% (G/3) with a water content of 10.63% (G/3), a CBR index of 25% (G/2), a dry density of 1.95 T/m3 (G/3) and a static modulus of 250 MPa (G/1). The CEBTP 1984 [22] classification does not classify the four lateritic gravels in a particular group. Some geotechnical values place them in group 1, others in group 2 or group 3. Figure 4 shows the swelling potential of the different lateritic gravels.

A - represents the directing coefficients of the straight lines delimiting the slightly swelling, moderately swelling, swelling and very swelling zones. According to Figure 4, the swelling potential (variation in the dimensions of lateritic gravel due to water absorption or evaporation) of the lateritic gravel LG1 is in the low-swelling zone with a liquidity limit of 17.45% and a clay content of 3.2%. Lateritic gravel LG2 contains clay, which places it in the slightly swelling category, despite its clay content of 3.875% and liquidity limit of 27.0%. Lateritic gravel LG3 contains clay which places it in the moderately swelling soil range with an LL of 24.20%, although its clay content is only 3.33%. Lateritic gravel GL4 contains swelling clay fines with a LL of 27.80%, although its clay content is 4.23%.

3.2. Activity, Relative Activity, Surface Activity, Cation Exchange Capacity Activity, Cation Exchange Capacity and Specific Surface Area of Lateritic Gravels

On the basis of the geotechnical properties given in table 1, the values of the intrinsic properties of lateritic gravels given in Table 5 are defined.

Table 5 SSA - specific surface area, CEC - cation exchange capacity, Sc - surface activity, ACEC - cation exchange capacity activity, Ac - activity, RA - relative activity, Ac/Sc - the ratio between activity and surface activity

Sample	SSA (m^2/g)	CEC (meq/100g)	Sc	ACEC	Ac	RA	Ac/Sc
LG1	46.05	5.88	15.93	2.035	3	0.19	0.19
LG2	73.26	9.36	18.90	2.41	3.53	0.19	0.19
LG3	54.42	6.95	16.98	2.17	3.18	0.19	0.19
LG4	89.99	11.5	21.28	2.78	3.97	0.19	0.19

From Table 5, the ratio of Ac activity to Sc surface activity presented by Locat et al., 2003 [23] can be simplified to RA relative activity defined by Quigley et al. 1985 [12] as the ratio of PI plasticity index to SSA specific surface area.

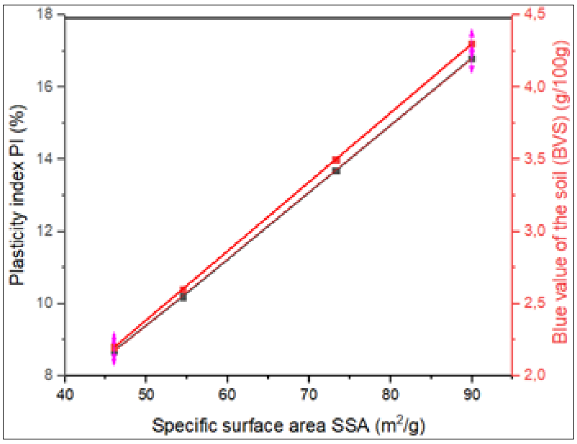


Figure 5 Correlation between plasticity index and blue value of the soil as a function of specific surface area

The soil blue value characterizes the activity of the clay fines in lateritic gravelly soils and reflects surface activity [18]. The specific surface depends on the mineralogy, organic composition and texture of lateritic gravelly soils [14,24-26]. The plasticity index is closely linked to the specific surface, but is not an intrinsic property of clay fines [18]. The plasticity index and the blue soil value normalized by the specific surface area of the clay fines fraction of lateritic gravels is a linear fit.

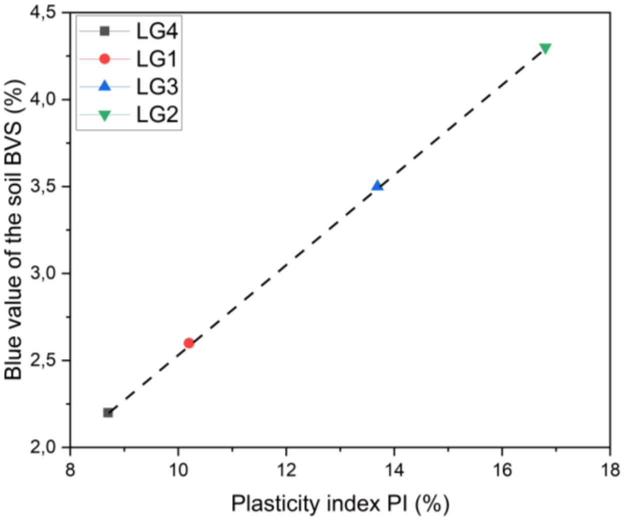


Figure 6 Relationship between soil blue value and plasticity index

In Figure 6, the blue value of the soil (BVS) shows the quantity and activity of the clay fraction in lateritic gravels [18]. The plasticity index is very closely linked to the specific surface area and the quantity and nature of the clay minerals [14,18]. In other words, the blue value of the soil as a function of the plasticity index is a linear fit.

$$VBS = a + b * IP \text{ .... } (10)$$

$$a = -0{,}04639 \pm 0{,}01292$$

$$b = 0{,}25887 \pm 0.0010$$

$$R^2 = 0{,}9999$$

BVS (g/100g) – blue value of the soil, PI (%) – Plasticity index et R^2 – determination of coefficient

Figure 7 shows the activity of the clay fines in the four lateritic gravels.

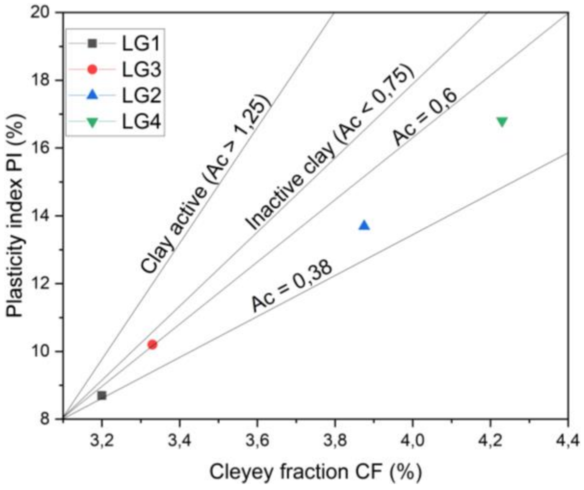


Figure 7 Activity of lateritic gravels

Ac activity characterizes the mineral contained in the fine clay of lateritic gravels. When the clay content is high enough, grains larger than two micrometers are embedded in the clay and hardly touch each other [24-26]. In Figure 7, Ac - are the directing coefficients of the straight lines delimiting the areas of activity of the clay fraction of lateritic gravels (inactive, normal and active). The lateritic gravel LG3 has an activity close to the coefficient 0.6 and LG1, LG2, LG4 have activities between 0.38 and 0.6, less than 0.75, i.e., the soils are inactive. The lateritic gravel LG4 is slightly plastic, but swells and is not likely to absorb much water because of its Ac inactivity (0.6). In the presence of water, lateritic gravel LG4 is unstable. This parameter must be taken into account during road construction. Figure 8 shows the relative activities of lateritic gravels.

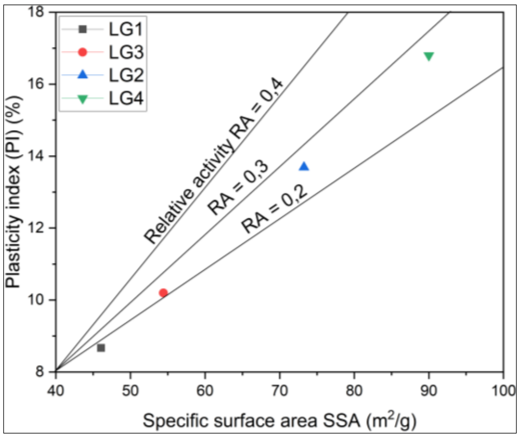


Figure 8 Relative activity of clay fines of lateritic gravels

In Figure 8, (RA) - are the directing coefficients of the straight lines delimiting the geological zones of the clay fines of the lateritic gravels. The relative activity values of 0.2, 0.3, 0.4 represent the geology of the sample sites of the four lateritic gravels. Relative activity determines the role played by specific surface area on soil plasticity. The plasticity index describes the quantity and type of clay, while the specific surface dominates the behavior of silt (LG1) and clays (LG2, LG3, LG4). The relative activities of the lateritic gravels LG1, LG2, LG3 and LG4 are very close RA (0.187-0.188). In other words, the geology of the lateritic gravels does not change significantly from one sampling site to another. The specific surface area of clays, defined as the ratio of specific surface area to clay fraction, used in conjunction with the plasticity index can help to identify the mineralogy of soils [23]. Activity and surface activity are normalized by the clay fraction, i.e., a linear plot of activity versus surface activity [23] simply suggests that a plot of plasticity index versus specific surface area should be linear.

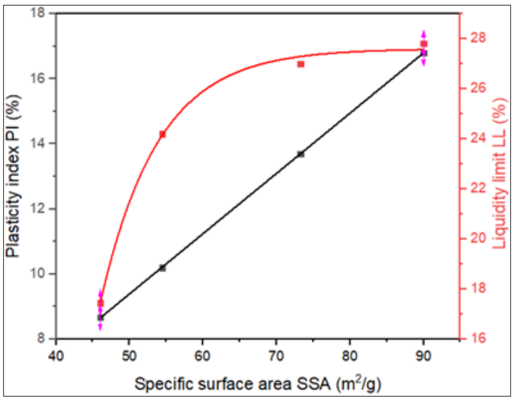


Figure 9 Evolution of the plasticity index and the liquidity limit as a function of the specific surface area of clay fines

From Figure 9, the range of water content from the liquid limit to the plastic limit depends essentially on the specific surface area. It has been shown that the liquid limit is related to the specific surface area, which varies considerably from one sample to another due to differences in mineralogy, organic composition and particle size distribution. The relationship between the plasticity index and the specific surface is a linear fit.

$$PI = a + b * SSA \quad (11)$$

$$a = 0{,}13821 \pm 0{,}02239$$

$$b = 0{,}18507 \pm 3{,}28761E - 4$$

$$R^2 = 0{,}999$$

PI (%) – Plasticity index, SSA (m^2/g) – Specific surface area, R^2 – determination of coefficient

From this correlation we can see that the plasticity index is very closely linked to the specific surface area as a function of mineralogy. The relationship between the liquidity limit and the specific surface is a non-linear fit. The curve is from the ExpDec1 model:

$$LL = A1 * exp\left(\frac{-SS}{t1}\right) + y0 \qquad (12)$$

$$y0 = 27{,}60201 \ \pm 0{,}31571$$

$$A1 = \ -3661{,}62521 \ \pm 2784{,}86033$$

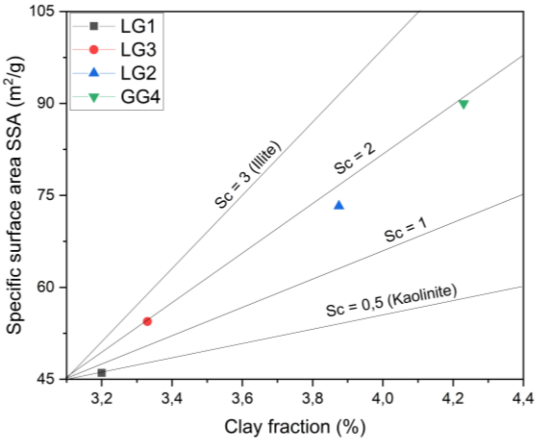
$$t1 = 7{,}81817 \ \pm 1{,}01872$$

$$Chi - Sqr\ (X^2) = 0{,}14447$$

$$R^2 = 0{,}993$$

PI (%) – plasticity index, SSA (m^2/g) – specific surface area, R^2 - determination of coefficient, Chi sqr (χ^2) - is used to test the independence of two random variables.

The mathematical model selected is the one with the highest coefficient of determination R^2 and the lowest Chi sqr (χ^2). From the relationship obtained, the range of water content from the liquidity limit (LL) to the plasticity limit (PL) depends on the specific surface area, which is itself linked to the liquidity limit (LL) [14,24]. Figure 10 shows the surface activity of lateritic gravels. The surface activity delimits the mineralogical formation zones from kaolinite to illite and the cation exchange capacity activity from illite to montmorillonite.

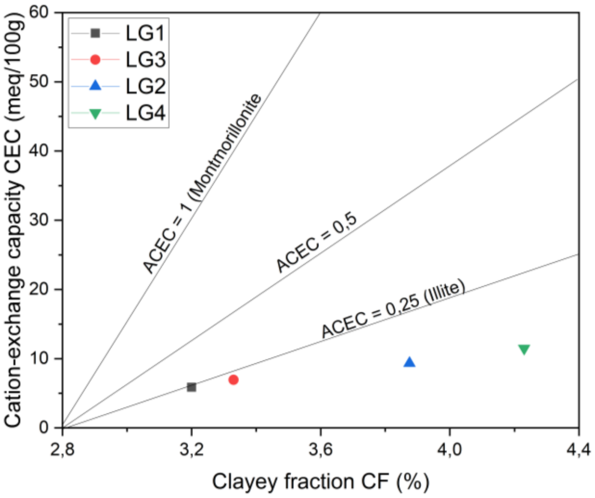


Sc - are the directing coefficients of the straight lines delimiting the areas of the mineralogical formations (kaolinite and illite).

Figure 10 Surface activity of clay fractions in lateritic gravels

Specific surface area refers to the actual surface area of a soil particle as opposed to its apparent surface area. This is of great importance for phenomena involving surfaces, such as adsorption and absorption. A number of scientific studies have linked specific surface area to the type and quantity of clay, water content, clay mineralogy, cation exchange capacity, liquidity limit and angle of internal friction in soils. Specific surface area has also been used to interpret physical characteristics such as shrink-swell potential. Specific surface area determined from adsorption methods can also be used to assess surface chemical properties such as adsorption of chemical elements and water retention capacity.

By using the specific surface area as a function of the clay fraction, new activity values can be defined. The surface activity shows distinct boundaries between geological formations. Figures 10-11 identify the minerals contained in the clay fines of the lateritic gravels on the basis of their intrinsic properties (specific surface area SSA and cation exchange capacity CEC). The three clayey gravels (LG1, LG2, LG3) and the silty gravel LG1 are generally composed of mixed mineral layers, which lie between the Sc coefficients. The four lateritic gravels contain kaolinite and have specific surface areas SSA (46.05 - 89.99 m^2/g). The specific surface areas of the clayey fines in the lateritic gravels are higher than those obtained with the clayey soils. [12,14,24]. The geology of lateritic gravels may be responsible for the disparity in specific surface area linked to particle size distribution and mineralogical and organic composition. The presence of kaolinite in lateritic gravel is of great importance in construction (brick making). Indeed, fine clays are known for their crystallizing properties, playing the role of mortar, especially when the soil contains organic matter [27]. This may therefore play a role in improving the mechanical strength of the lateritic gravels studied.



ACEC - are the directing coefficients of the straight lines delimiting the areas of the mineralogical formations (Illite and Montmorillonite). The lateritic gravels GL1, GL2, GL3 and GL4 have a coefficient of activity of the cation exchange capacity lower than ACEC = 0.25, i.e., these lateritic gravels are composed exclusively of the mineral kaolinite.

Figure 11 Cation exchange capacity of lateritic gravels.

3.3. X-ray diffraction analysis (XRD) – diffractograms

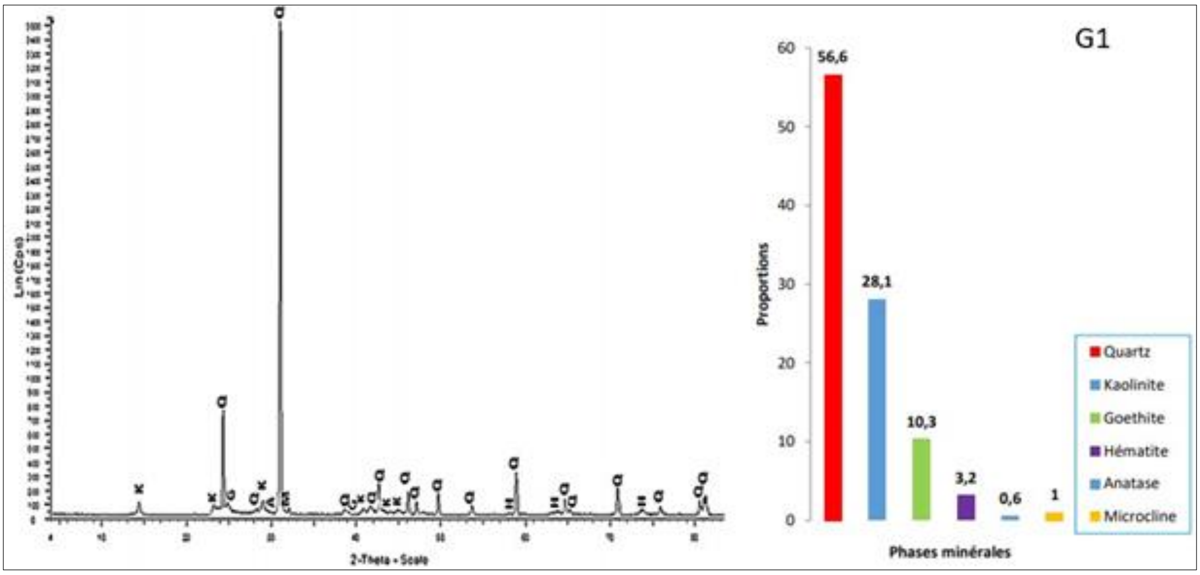


Figure 12 Microstructure of lateritic gravel (LG1)

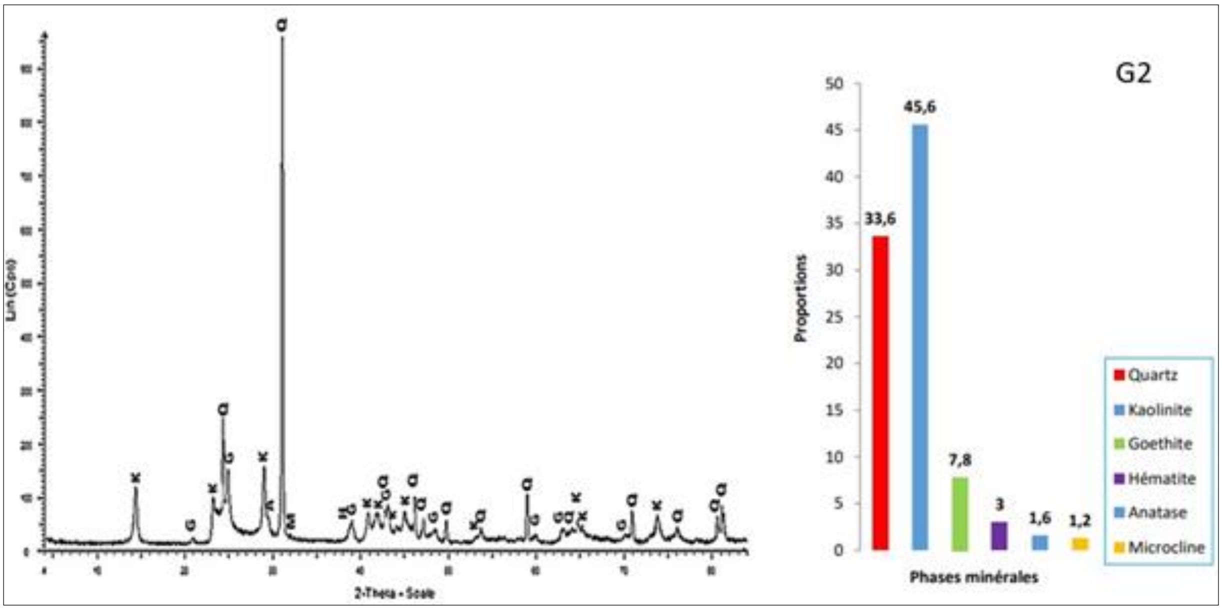


Figure 13 Microstructure of lateritic gravel (LG2)

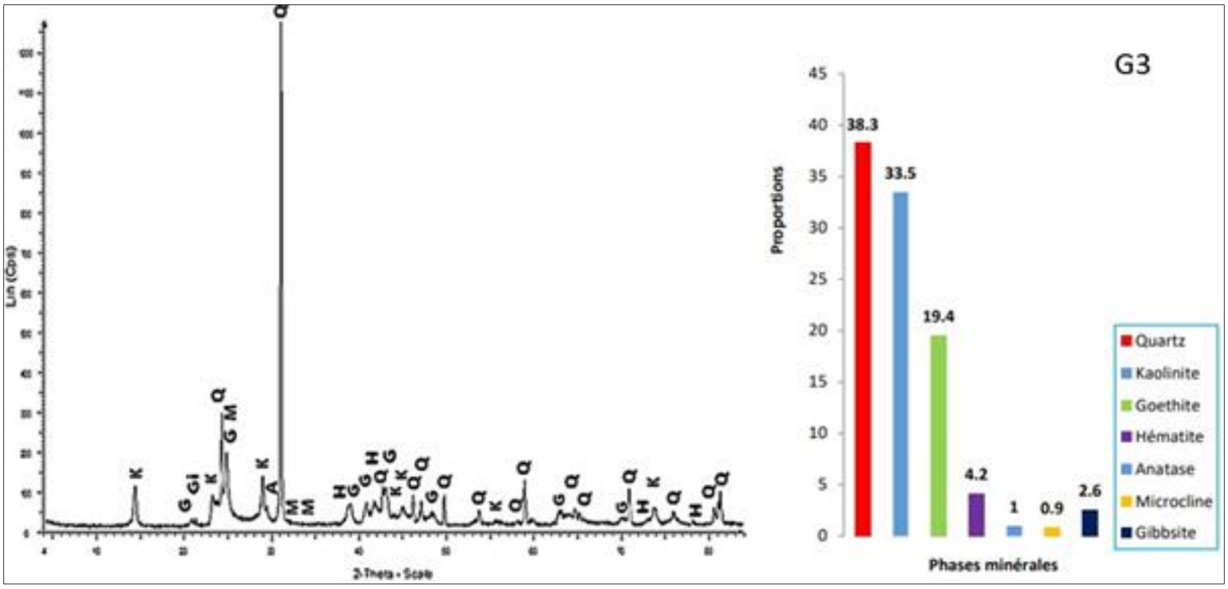


Figure 14 Microstructure of lateritic gravel (LG3)

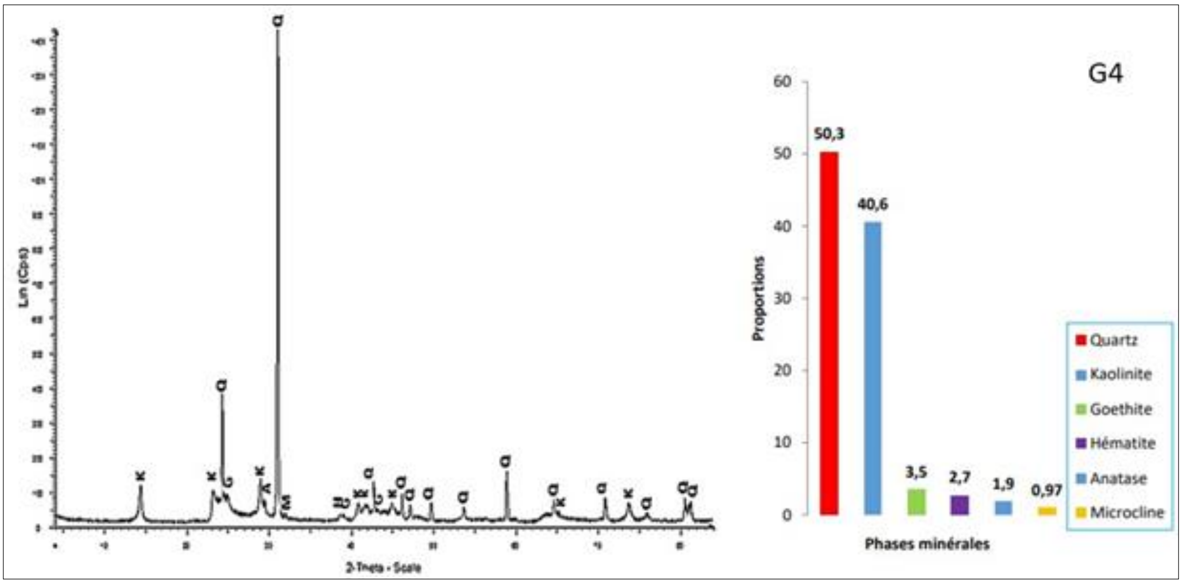


Figure 15 Microstructure of lateritic gravel (LG4)

The XRD analyses carried out on the powders from the lateritic sample revealed minerals common to all the samples: quartz, kaolinite, goethite, hematite, anatase. Hydrated aluminum oxides (gibbsite Al $(OH)_3$) were only found in sample LG3 (Figure 14). These minerals, although common to most of the samples analyzed, vary in proportion from one sample to another. Once the mineral phases had been identified, they were quantified using the Riedvelt method.

Sample LG1 (Figure 12): the amount of quartz (56.6%) is very high. The kaolinite content (28.1%) is almost half that of quartz. The matrix therefore contains more silica than clay. Iron oxides are relatively moderately in content: 10.3% for goethite and 3.2% for hematite, giving a total of 13.5%. Titanium oxides (anatase) are not very present (0.6%) and microcline (1%) is found in diffuse traces. Sample LG2 (Figure 14): the dominant mineral in this sample is kaolinite (45.6%) followed by quartz (33.6%). Iron oxides are moderately high, totaling 10.8% for the two forms of iron oxides found (goethite and hematite). Titanium oxides and microcline are weakly present (1.6 and 1.2%). Sample LG3 (Figure 13): Quartz and kaolinite contents, are lower in this sample, at 38.3% and 33.5% respectively. On the other hand, iron oxides are present in large quantities, with a content of 19.4% for goethite and 4.2% for hematite. A small quantity of aluminum oxides (gibbsite = 2.6%) was also found in this sample. Anatase and microcline are present in trace amounts (1 and 0.9%). Sample LG4 (Figure 15): this sample has a high silica and kaolinite content, 50.3 and 40.6% respectively. The iron oxide content (goethite and hematite) is low, at 3.5 and 2.7% respectively. Titanium oxides (anatase) and microcline are present in trace amounts (1.9 and 0.97% respectively).

4. Discussion

The grading curves of the lateritic gravels are spread out (Cu > 4), but they are poorly calibrated, the coefficient of curvature Cc (2.31-3599.01) does not include the range 1 < Cc < 2 [18]. In relation to the GTR 92 [18] classification, the four lateritic gravels are in classes B_5 (LG1) and B_6 (LG2, LG3, LG4), like most of the lateritic gravels studied. The lateritic gravel LG1 is a silt [20], weakly plastic (Figure 3), weakly swelling (Figure 4), class A-4 and A-2-4 [19]. Lateritic gravel LG2 and LG3 are clays [20], weakly plastic (Figure 3), moderately swelling (Figure 4), class A-6 and A-2-6 [19]. The lateritic gravel LG4 is a clay [20], weakly plastic (Figure 3), swelling (Figure 4), class A-6 and A-2-6 [19]. According to Table 3, the clay fines of the four lateritic gravelly have specific surface areas SSA (46.05 - 89.99 m^2/g). Mitchell (1976), Amy Cerato et al (2005), Louis Ahouet et al, 2022 [13,14,24] found that the specific surface area of clayey fines containing kaolinite as a mineral had respective specific surface areas of SSA (10 - 40 m^2/g), SSA (15 - 50.51 m^2/g) and SSA (4.40 - 20.51 m^2/g). Therefore, the type of clay mineral present in the soil is of major importance in determining the effect of specific surface area on the properties of lateritic gravels. Since the surface of a soil is controlled by the particle size distribution and mineralogy of the clay fines, their surface can be considered an inherent property of lateritic gravels. Although the geology of lateritic gravels is similar, the mineral content differs and may be responsible for the disparity in specific surface area. Indeed, Amy Cerato et al., 2005 [14] have shown that, despite the fact that clays account for most of the surface area of all the constituents of these minerals, they have different specific surface areas. In fact, specific surface varies greatly from one soil to another due to mineralogical differences, organic composition and particle size distribution. Kaolinite in lateritic gravel is of great importance, especially for making solid bricks. The clay containing kaolinite is known for its crystallizing properties, acting as a mortar that can improve the mechanical strength of lateritic gravel [27]. From Table 3, the ratio between Ac activity and Sc surface activity presented by Locat et al., 2003 [23], can be simplified to RA relative activity defined as the ratio between PI plasticity index and SSA specific surface [12]. In Figure 7, the four lateritic gravelly are inactive, with Ac activities below 0.75. The C line proposed by Locat et al. 2003 [23] (Fig. 14) does not vary according to the mineralogy of the soils, but rather according to the geology and nature of the soils. In other words, surface activity may not describe the behavior of clay fines in lateritic gravelly soils of the four geological formations, as a function of mineral content and sampling location. The results in figures 10-15 confirm the presence of kaolinite in the four lateritic gravel samples.

5. Conclusion

The four samples of lateritic gravel have spread grain sizes with a poorly graded grain distribution. These lateritic gravels contain clayey and silty fines, are weakly plastic, weakly swelling and are inactive. The plasticity index is very closely linked to the specific surface area and the quantity and nature of the clay minerals. The relationship between the plasticity index and the blue value of the soil is a linear fit. Specific surface area and cation exchange capacity (CEC) as a function of clay fraction and specific surface area as a function of CEC are linear fits. Activity provides an approximate method for determining mineralogy, whereas the plasticity index is not really an intrinsic property of fine soils. The behavior of lateritic gravels is characterized by their specific surface area and cation exchange capacity, which are two fundamental properties for clayey fines. Relative activity determines the role played by specific surface area on soil plasticity. The surface activity delimits the zones of mineralogical formations from kaolinite to illite and the activity of the cation exchange capacity from illite to montmorillonite. The blue value of the soil characterizes the activity of the clays contained in the soil and reflects surface activity. The specific surface depends on the mineralogy, organic composition and texture of the soil.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no competing interests.

References

[1] Nwaiwu, C. M. O., Alkali, I. B. K., Ahmed, U. A. Properties of ironstone lateritic gravels in relation to gravel road pavement construction. Geotechnical and Geological Engineering, 24, 2006.

[2] Souley Issiakou, M. Characterization and recovery of lateritic materials used in road construction in Niger. Universitéde Bordeaux, 2016.

[3] Ndiaye, M. Contribution to the study of lateritic soils in Senegal and Brazil. University of Paris-Est, 2013.

[4] Quadri1, H. A., Adeyemi1, O. A., Olafusi, O. S. Investigation of the geotechnical engineering properties of laterite as a subgrade and base material for road constructions in Nigeria. Civil and Environmental Research, 2, 2012.

[5] Ndiaye, M., Magnan, J.-P., Cissé, I. K., Cissé, L. Study of the improvement of laterites in Senegal by adding sand. Bulletin of Laboratory Road and Bridge, 280- 281, 2013

[6] Madjadoumbaye, J., Kamdjo, G., Mbessa, M., Defo, F. E. H., Tamo, T. T. Possibilities for improving the bearing capacity of laterite with a vegetable shell: the shell of palm kernels. Electronic Journal of Geotechnical Engineering, 18, 2013.

[7] Louis Ahouet, Raymond Gentil Elenga, Stévyna Bouyila, Mondésir Ngoulou, Eric Kengue. Improvement of the geotechnical properties of lateritic gravel by adding crushed alluvial gravel 0/31.5. Vol. 3(1), pp. 1-6, Online January 2019, RAMReS 2018 - Published Online 2018 - http://publication.lecames.org/

[8] Molenaara, A. A. A. Durable and Sustainable Road Constructions for Developing Countries. Procedia Engineering 54, 2013.

[9] Cocks, G., Keeley, R., Leek, C., Foley, P., Bond, T., Crey, A., Paige-Green, P., Emery, S., Clayton, R., Iness, Mc D., Les Marchant. The use of naturally occuring materials for pavements in western australia. Austalian Geomechanics, 30, 1, 2015.

[10] Weinert, H. H. The natural road construction materials of South Africa. Academica, Pretoria, Cape Town, 1980.

[11] Skempton, A.W. 1953. The colloidal "Activity" of clays. Proceedings of the 3rd International Conference of Soil Mechanics and Foundation Engineering. Switzerland, vol. 1. 57-60.

[12] Quigley, R.M., Sethis, A.J., Boonsinsuk, P., Sheeren, D.E. and Yong, R.N. (1985) Geologic Controls on Soil Composition and Properties, Lake Ojibway Clay Plain, Matagami, Quebec. Canadian Geotechnical Journal, 22, 491-500. https://doi.org/10.1139/t85-069

[13] Mitchell, J.K. and Soga, K. (1976) Fundamentals of Soil Behavior. 3rd Edition, 561 p. https://kupdf.net/

[14] Amy Cerato, Alan J. Lutenegger (2005). Activity, Relative Activity and Specific Surface Area of Fine – Grained Soils. Conference paper. https://www.researchgate.net/publication/255585812.

[15] NF P 94-056 (1996) French Standard. Soils: Recognition and Tests. Granulometric Analysis. Method by Dry Sieving after Washing, French Association for Standardization, 5-15.

[16] NF P94-057 (1992) French Standard. Soils: Recognition and Tests. Granulometric Analysis. Sedimentation Method, French Association for Standardization, 4-17.

[17] NF P94-051 (1993) French Standard. Soils: Recognition and Tests. Determination of Atterberg Limits. Limit of Liquidity at the Cup-Limit of Plasticity at the Roller. French Association for Standardization, 4-14.

[18] NF P 11-300 (1992) Construction of Earthworks—Classification of Materials for Use in the Construction of Embankments and Subgrades of Road Infrastructure.

[19] AASHTO T88-70 (2020). The American Association of State Highway and Transportation Officials system is used worldwide for road construction.

[20] USCS (Unified Soil Classification System). This system is applicable to projects such as dams, foundations and runways. The basic principle of this system is to classify coarse-grained soils according to their grain size and fine-grained soils according to their plasticity.

[21] NF P94-068 (1998) French Standard. Soils: Investigation and Testing - Measuring of the Methylene Blue Adsorption Capacity of a Rocky Soil. Determination of the Methylene Blue of a Soil by Means of the Strain Test, October 1998.

[22] C.E.B.T.P (1984): Practical guide to pavement design for tropical countries, French Ministry of Cooperation.

[23] Locat, J., Tanaka, H., Tan, T.S., Desari, G.R. and Lee, H. (2003) Natural Soils: Geotechnical Behavior and Geologic Knowledge. Characterization and Engineering Properties of Natural Soil, No. 1, 3-28.

[24] Ahouet, L., Ngoulou, M.O., Okina, S.N. and Dzaba, S. (2022) Geotechnical Characterization of Termite Mound Soils of Congo. Open Journal of Civil Engineering, 12, 370-389. https://doi.org/10.4236/ojce.2022.123021

[25] Louis Ahouet, Sylvain Ndinga Okina, Mondésire Odilon Ngoulou, Bockou Ekockaut J. Arsène. Study of Correlations between Particle Size Analysis and Intrinsic Properties of Termite Mound Soils Cubitermes sp. 2022, Vol. 10, No.1, 8-15, https://doi:10.12691/ajmse-10-1-2.

[26] Louis Ahouet, Sorel Dzaba, B. D. Mbossa Elenga, Sylvain Ndinga Okina, Fabien T. Kimbatsa. Characterization of the Activity, Mineralogy and Correlations between the Properties of Clayey Soils. Journal of Minerals and Materials Characterization and Engineering, 2022, Vol. 10, 410-428. https://doi.org/10.4236/jmmce.2022.105029

[27] Millogo, Y., Hajjaji, M. and Morel, J.C. (2011) Physical Properties, Microstructure and Mineralogy of Termite Mound Material Considered as Construction Materials. Applied Clay Science, 52, 160-164. https://doi.org/10.1016/j.clay.2011.02.016