Research Article

Geotechnical, mechanical and geological characterization of lateritic gravels of Boumpial (Cameroon) used in road construction

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ABSTRACT

The present study deals with a geological, mechanical and geotechnical characterization of lateritic gravels developed on gneiss in the Boumpial region (East Cameroon). The raw materials description was done during the fieldwork. The collected samples were subjected to mechanical and geotechnical tests. The rock sample powder and lateritic gravels mineralogy were determined using optical microscopy and X-rays diffraction on the total fractions and the fine ones. The overall chemical compositions of major elements of lateritic gravels were determined by the use of X-fluorescence and titrimetry. The results obtained show that lateritic gravels of East Cameroon present: fines (18 wt.%), plasticity index (21%), CBR (72%), compressive strength (1.27 Mpa) and tensile strength of 0.08Mpa. The X-ray diffraction and the chemical analysis revealed 34 wt.% kaolinite, 24 wt.% of hematite, 13 wt.% of goethite, 11 wt.% of quartz, 10 wt.% of gibbsite and 1 wt.% of anatase. The silica/sesquioxides ratio (1.04) showed that the lateritic gravels is suitable for the sub-base course in road construction. By mixing 20 wt.% of the 5/20 rock fragment fraction (with LA< 60) and 80 wt.% of lateritic gravels (CBR = 92 %), the studied material can be employed for constructing foundations.

Keywords: Lateritic gravels; Geotechnical and mechanical tests; Mineralogical and chemical analyses; Road construction; Cameroon

RÉSUMÉ

Les graveleux latéritiques sont des matériaux largement utilisés en construction routière en zone intertropicale à cause de leur abondance. Il a été constaté que ces matériaux, choisis uniquement sur la base de leurs propriétés géotechniques, se sont mal comportés sur les chaussées. Par conséquence, quelques chercheurs ont suggéré d'associer les analyses chimiques et minéralogiques aux essais géotechniques classiques, dans le but de mieux évaluer leur aptitude comme matière première de couche de chaussées. Les résultats des essais géotechniques réalisés sur les graveleux latéritiques de la région de Boumpial (Est Cameroun) sont : particules fines (18 %), IP (21 %), CBR (72 %), Rc (1,27 Mpa), Rt (0,08 Mpa). Les analyses minéralogiques (DRX) et les données chimiques montrent que ces graveleux latéritiques se composent de kaolinite (34 %), d'hématite (24 %), de goethite (13 %), de quartz (11 %), de gibbsite (10 %) et d'anatase (1 %). La valeur du rapport silice/sesquioxydes (1,04) indique que ces graveleux latéritiques sont aptes à une utilisation comme matériau de couche de fondation. De plus, le mélange de 20 % de la fraction granulométrique 5/20 des gneiss (LA < 60) avec 80 % de graveleux latéritiques de la région de Boumpial (CBR = 92 %) est utilisable comme matériau de couche de base.

Mots-clés : Graveleux latéritiques, essais géotechniques et mécaniques, minéralogie et chimie, construction routière, Est Cameroun.

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INTRODUCTION

Because of their abundance in countries of the inter-tropical zone, lateritic gravels are used in road construction as material of sub-base or base (Millogo et al., 2008). They are movable ground formed in tropical environment, composed of granular fraction constituted of pisolites or ferruginous nodules encrusted in a limono-clayey fine matrix (Bagarre,1990; Millogo et al., 2008).

In Central Africa, some studies were documented concerning the geotechnical and mechanical characteristics (Ekodeck, 1984; Onana, 2010) and the genesis (Ekodeck, 1984) on the lateritic soils and mainly on those of Cameroon. The roads permitting, on one hand, the commercial exchanges between countries of Central Africa area and on other hand the connection between principal productive towns, thus playing a vital social and economic role in the developing countries.

In Cameroon, like in most of African countries, the lateric gravels are considered to be good materials for the road construction (Gidigasu, 1980; Millogo et al., 2008). They are characterized by low swelling under humid atmosphere. Although they are widely used, few scientific works have been dedicated to them (Lompo, 1980; Ekodeck et Kamgang, 2002; Millogo et al., 2008;Ekodeck et Kamgang, 2011). Generally, their choice in road engineering is essentially based on their geotechnical properties which are determined by known tests: the particle size distribution, the Atterberg's limits, the references of the Proctor modified and the Californian Bearing ratio (CBR) (Lompo, 1980; Ekodeck, 1984; Millogo et al., 2008).Nevertheless, it was observed that the mineralogical and chemical compositions as well as microstructure are rarely used for the choice of the lateritic gravels in road construction(Ekodeck et Kamgang, 2002; Millogo et al., 2008;Ekodeck et Kamgang, 2011). The Cameroon road network is subject to relatively fast degradation traditionally attributed (1) to sub-dimensioning, either by economic measures or to causes related to poorly realized or adapted geotechnical study, or due to poorly adapted or poorly used materials, finally due to inappropriate dimensioning criteria, (2) to the execution of works in the non-respect of the rules of art, (3) to the lack of frequent maintenance, (4) to the overloading by some vehicles relative to the capacity set during the dimensioning of some vehicles. However, it is realized that even when the causes of degradation have been avoided, they still emerge. This behavior could be related to the insufficiencyof the geotechnical tests justifying the choice of the lateriticgravels destined to the road construction. However, some authors in the Sahel (Tockol et al., 1994)believe that chemical and mineralogical tests must be conducted on the lateritic gravels, in addition to the geotechnical tests so as to better apprehend the conditions under which such materials will be used in road construction.

The aim of the present work is to make a study which associates the geotechnical and mechanical characteristics to mineralogical and chemical properties of lateritic gravels of Cameroon. This is in view to evaluate its suitability for base course material in road section between Boumpial (East Cameroon) and Centrafrican Republic.

2. ANALYTICAL PROCEDURES

The studied raw material is lateritic gravels from Boumpial, a locality of the East of Cameroon (Fig. 1). The zone of sampling is constituted by panafrican formations with metamorphic dominance formations (gneiss). The raw material used in this study comes from a pushed lateritisation of the metamorphic lands.

Twenty pits have been dug along the site. The average thickness of the exploitable profile was

1.5 m. The profiles were generally constituted of three levels: the lower lateritic level, the medium nodular level and the loose clayey one. Four shares of 50 kg were taken in the medium nodular level. A single mixture was made from the 80 shares appropriated to realize the analyses.

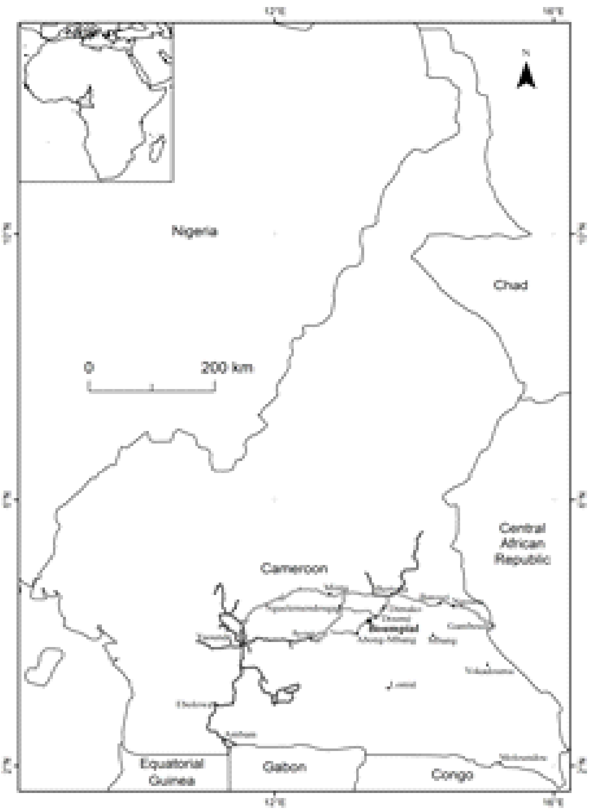

Fig. 1. Location map of Boumpial region (East Cameroon)

The mechanical and geotechnical tests have been made in the national laboratory of civil engineering of Cameroon A sufficient quantity of the single mixture was ground in an agate mortar until a particle size < 80 ìm for the determination of the specific gravity.

The particle size distribution was achieved according to NF P18-560 (particles size distribution by dry sieving) and NF P94-057 (particles size distribution by sedimentation) standards. The liquid limit was measured by the Casagrande's dish method (w_L) and the plastic limit by the roller method (w_P). These measurements were realized according to NF P94-051 standard.The blue methylene value (V_b) was determined on the total sample according to NF EN 933-9.The optimum moisture content (OMC) and the maximum dry density (MDD) were determined according to NFP94-093 standard.The CBR test after 4 days soaking was determined according to NF P94-078 standard. The punching was achieved with a press Seditech coupled with a computer.

The mechanical properties were characterized both with the compressive strength, the strain-stress registration and with the tensile strength (Brazilian test). Four cylindrical test-tubes were molded in CBR moulds (diameter = height = 15.2 cm) at the optimum Proctor modified and then setting in equilibrium under controlled atmosphere during 28 days. The compressive strength was achieved according to NF P18-406 standard and the tensile strength test according to NF P18-408 standard. The apparatus used for these tests is a universal press type Seditech coupled to a computer for the registration and the treatment of the data. The LA values of gneiss were determined according to NF P18-573 standard.

The mineralogy of the materials was determined by X-ray diffraction on the total fine fractions. The analyses were carried out using a diffractometer (Philips 1720 model) with a cobalt tube (Co = 1.79021 Å) at the Geosciences Laboratories Geolabs (Canada). Samples were pulverized with an agate mortar and pistle; the resulting powder was picked up on a piece of tape before being irradiated with Cu K radiation in a diffractometer. The resulting diffraction spectra were compared with a computerized data base of common minerals, whose automatic mineral-matching function was assisted by operator identification of phases consistent with the known compositions of the materials. Phase proportions were estimated by the peak-matching program without calibration to synthetic mixtures of known phase proportions.

The chemical composition was determined by X-ray fluorescence after sample ignition at the Geosciences Laboratories Geolabs (Canada). Sample powders were ignited and then melted with lithium tetraborate flux before analysis using Rigaku RIX-3000 wavelength-dispersive X-ray fluorescence spectrometer. International standards BIR-1-0949, SDU-1-0295 and SDU-1-0296 as well as in-house standards were run with the unknowns; comparisons of measured and reference values are available upon request. Samples were crushed using a jaw crusher with steel plates and pulverized in a planetary ball mill made of 99.8% Al_2O_3. A two-step loss of ignition (LOI) determination was employed. Powders were first heated to 105°C under nitrogen to drive off adsorbed moisture, before being ignited at 1000 °C under oxygen to drive off remaining volatiles and oxidize Fe.

RESULTS

Geotechnical and mechanical characteristics

The determined loss of ignition for the raw material is 14.02 wt.%. This value expresses relative important content of clay minerals (Mbumbia et al., 2000).The measured specific gravity (27.6) is similar to those of kaolinite; presumably of its appreciable content.

The particles size distribution of the basic raw material (Fig. 2) shows that the sample consists of 27.0 wt.% of skeleton, 20.0 wt.% of mortar, 18.0 wt.% of fine fraction and 8.1 wt.% of clayey fraction. The geotechnical characteristics of the sample are reported in table 1. These results permit to deduce that the class of this sample is A-2-7 according to US HRB. The plasticity index (21%)which is more than 12%, shows that this material is plastic (Robitaille et Tremblay, 1997). This important plasticity is presumably a consequence of the high content of clayey minerals and low abundance of quartz in the skeleton, mortar and fine particles (Ekodeck,

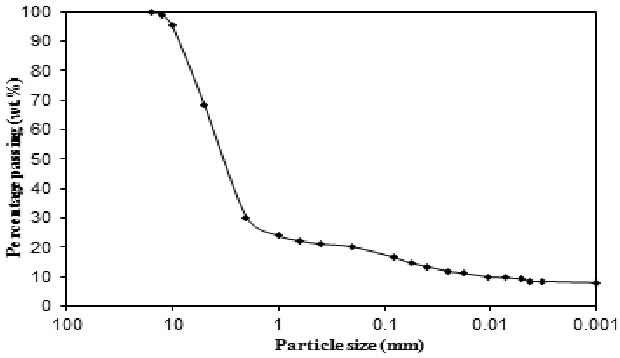

Fig. 2. Particle size distribution curve of the sample

Table 1: Geotechnical characteristics of the sample

Geotechnical characteristics	Results
Particle size distribution (wt.%)	
< 2 mm (skelton)	27.0
< 0.425 mm (mortar)	20.0
< 80 μm (fine particles)	18.0
< 2 μm (clays)	5.0
Atterberg limits	
Liquid limit, w_L (%)	54
Plasticity limit, w_P (%)	33
Plasticity index, PI (%)	21
Blue methylene value of the total sample (g/100 g)	1.3
Modified proctor	
Optimum moisture content (OMC) (%)	10.7
Maximum dry density (MDD) (kN/m^3)	27.8
CBR at 95% of MDD (%)	72

1976). The high methylene blue value (1.3 g/ 100g) of the concerned material, which is corroborated with the plasticity index and loss of ignition, confirmed the abundance of clayey minerals. The optimum moisture content (OMC), the maximum dry density (MDD) and the CBR at 95% of MDD (10.7%, 27.8 kN/m^3 and 72% respectively) allow concluding that the raw material may be convenient for sub-base course in road construction (CEBTP, 1972). However, its use as base course materials requires stabilization with crushed hard or of hydraulic binders (Lompo, 1980; Messou, 1980; Autret, 1983).

The strain–stress curve (Fig. 3)of the sample show that the mechanism of rupture of this one is of the ductile type with a well-marked elasticity phase. It is a flexible sample; it is therefore adequate for the road construction (Ekodeck, 1984).

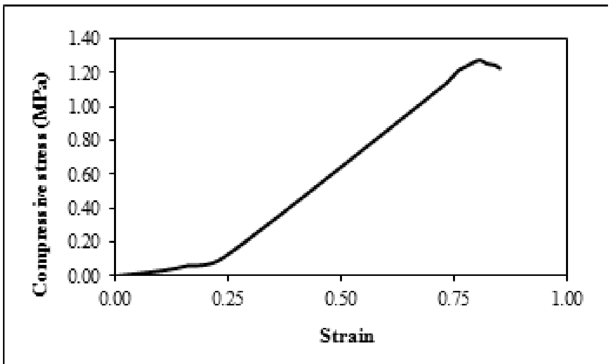

Fig. 3. Stress–strain curve of the sample cured 28 days

The compressive and tensile strengths were 1.27 and 0.08 MPa, respectively. The compressive strength is in the range 0.5–1.5 Mpa, these materials are suitable for sub-base layer according to the data reported in the literature (Millogo et al., 2008; Messou, 1980). Nevertheless the compressive strength is higher than the compressive strengths reported by Messou(1980),Bagarre(1990) and Attoh-Okine(1995) respectively, with the lateritic gravels of Ivory Coast, Cameroon and Ghana. The value of this parameter is similar to that presents by Millogo et al., (2008) in Burkina Faso (1.27 Mpa) despite of its kaolinite content (34 wt.%). This is due to the low content of iron minerals (hematite and goethite) in these lateritic gravels in relation to the studied sample. The sample is suitable for sub-base course because it presents better mechanical properties of this type of materials.

The linear elasticity modulus, estimated by plotting the mean curve (Fig. 3), was 160 Mpa. This value is higher than that obtained by Millogo et al., (2008) on the lateritic gravels of Burkina Faso. This value shows that those lateritic gravels of Boumpial are flexible material as it is deduced from the strain-stress curve. The raw lateritic gravels of Africa are characterized by low elasticity modulus, generally less than 200 Mpa.

Geological characteristics

Chemical composition

The chemical composition of the sample (Tab. 2) showed the presence of appreciable amount of Fe_2O_3 (35.80 wt.%), SiO_2 (26.35 wt.%) and Al_2O_3 (19.98 wt.%) and a weak content of TiO_2 (1.28 wt.%).These results permit to think that alumino-silicates compounds and iron minerals seem to predominate in those materials.

Table 2: Chemical composition of the sample

Oxides	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	MnO	Na_2O	K_2O	TiO_2	FeO	P_2O_5	Cr_2O_3	NiO	LOI 1000°C	Total
wt.%	26.35	19.98	35.80	0.09	0.04	0.05	0.07	0.08	1.28	0.54	0.24	0.09	0.01	14.02	98.64

Mineralogical composition

The diffractogram of the <80 µm sample powder (Fig. 4) permits the detection of the following mineral phases: kaolinite, hematite, goethite, quartz, gibbsite and anatase.

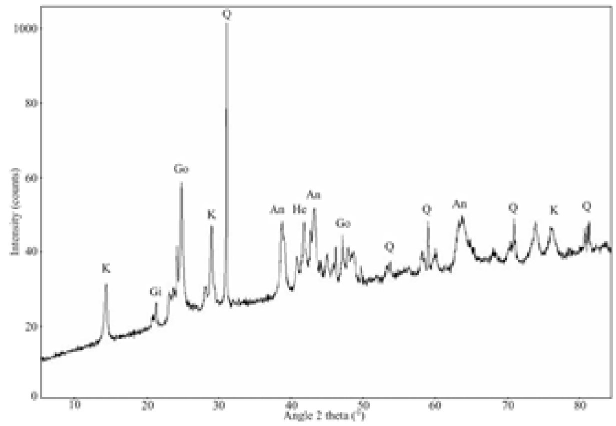

Fig. 4. XRD spectrum of the total sample
K = kaolinite, Q = quartz, He = hematite, G = Goethite, Gi = gibbsite, An = Anatase.

These minerals are usually present in the lateritic soils (Ekodeck, 1984; Mbumbia et al., 2000). The iron minerals are predominant in the fraction of thicker granulometry(Millogo et al., 2008). Kaolinite minerals are also present in that fraction were they are protected by hematite (Ndjigui et al., 2008). The presence of gibbsite suggests more humid climatic conditions in relation to those of Burkina-Faso and consequently a high degree of weathering. Swelling clayey species such smectites are absent in the studied material. Those minerals increase the plasticity of material and have detrimental effects in their mechanical properties (Ekodeck, 1976).

Table 3 gives the semi-quantitative mineralogical composition of the mineral phases of the sample.

It reports a relative important proportion of kaolinite (34 wt.%) which is in relation with the loss of ignition (14.02 wt.%), the plasticity index (21 %) and the methylene blue value (1.3 g/100 g). The amounts of hematite is 24 wt.%; the proportion of goethite (13 wt.%) and gibbsite (10 wt.%), oxyhydroxides of iron and aluminium, respectively, are relatively important. Those minerals are in relation with Fe_2O_3 (35.80 wt.%), Al_2O_3 (19.98 wt.%) and loss of ignition contents. The amount of quartz and anatase are 11 wt.% and 1 wt.% respectively.

Table 3: Semi-quantitative mineralogical composition of the sample

Crystallized minerals	Kaolinite	Hematite	Goethite	Quartz	Gibbsite	Anatase	Total
Mineralogical composition (wt.%)	34	24	13	11	10	1	93

Discussion

The geotechnical results obtained and those concerning the use of Central African tropical soils in road construction reveal that the studied material is convenient for the execution of sub-base layers in road construction. This is justified by the fine fraction amount (18 wt.%) which is less than 30 wt.% and the fact that, the product of the plasticity index and fine clayey fraction content (f.PI) which is 378, is higher than the maximum value (100) recommended for base material (Gidigasu, 1983).

Geotechnical standards for layers in road pavement take into account the traffic intensity and the thickness of the layers. On the Ayos-Boumpial - Bonis-Central African Republic road section, the traffic is on T3 type. This traffic is dense; average 1000–3000 vehicles per day will pass on this road section because of its importance for commercial activities between Cameroon and Central African Republic.The admitted CBR values for sub-base and base materials supporting such traffic intensity are 30 and 80% minimum respectively (CEBTP, 1972). Even taking into account these specifications, the studied sample is convenient as sub-base material.

The geotechnical properties of the sample from Boumpial are globally better than those reported for some laterites from Cameroon, Ghana, Ivory Coast and Burkina Faso (Gidigasu, 1972; Bagarre, 1990; Millogo et al., 2008). Nevertheless, the proportion of fine fraction (18 wt.%) is higher than that of Burkina Faso (10.5 wt.%). The differences could be related to the mode of formation of lateritic soils and the type of climate under which they were formed.

The laterites of Ghana and Ivory Coast are derived from the weathering of granites and phyllites (Gidigasu, 1972). Those of Burkina Faso were developed from the weathering of sandstone and granite (Millogo et al., 2008). Those from Boumpial are formed on gneiss; those lateritic gravels are rich in hematite and goethite and these minerals contribute to the improvement of the geotechnical and mechanical characteristics and road stability.

The application of geotechnical and mechanical procedures for the identification and evaluation of potential applications in road construction of some lateritic soils often lead to errors considering the evolution of these raw materials with time. For instance, some lateritic materials which fulfill all the conditions in the time of road construction have shown a poor behaviour on the road with time. This is related to their chemical and mineralogical composition (Millogo et al., 2008). For this reason, geotechnical and mechanical tests should be supplemented with chemical and mineralogical analyses so as to characterize that raw materials intended for road construction. Generally, one of the most important criteria for the choice of a laterite depends on the silica/sesquioxide ratio (Fall, 1993; Mahalinger-Iyer et al., 1997). This ratio obtained for Boumpial is 1.04. This sample could be used on road construction with no risk of degradation in the future (Tockol et al., 1994). However, this latter ratio is less than 2.5 and thus the material is not adequate for the construction of a base course. In fact, the base course requires the use of raw materials with better mechanical performances, with a silica/sesquioxide ratio ranging between 2.5 and 6 (Mahalinger-Iyer et al., 1997).

The use of this materials mixed with gravels 0/31.5 (with LA index < 60%) have shown that for mixtures of 20 wt.% of 0/31.5 and 80 wt.% of laterites, 25 wt.% of 0/31.5 and 75 wt.% of laterites and 30 wt.% of 0/31.5 and 70 wt.% of laterites, the CBR decreases with respect to the CBR of the natural materials (72%) because of an increase in proportion of the fine fraction (Table 4). Nevertheless, considering the fraction 5/20, for a mixture of 20 wt.% of 5/20 and 80 wt.% of laterite, a CBR of 92% is achieved (Table 5).

The geotechnical and mechanical characteristics of the lateritic gravels are essentially due to their chemical and mineralogical compositions as well as the distribution of the different minerals present (Ekodeck, 1984; Ekodeck, 1976). The good mechanical characteristics of this compacted material is due to the iron minerals hematite and goethite (Ekodeck, 1984).

The present study reveals that the mineralogical composition and the geotechnical properties of a raw material destined for road construction should be simultaneously known so as allow a judicious choice of material to be used (Millogo et al., 2008). Moreover, lateritic gravels having a CBR greater than 60% might be used in the base layer after mixing with rock gravel whose Los Angeles index value less than 60% and the 5/20 fraction is 20 wt.% and 80 wt.% for laterite. The materials of Boumpial have a swelling potential less than 0.1%. They are thus classified among non-swelling clays (Millogo et al., 2008).

Table 4: Swelling potential of soils according to their plasticity index

Swelling potential	ε_s	PI (%)
Low	0–1.5	0–10
Moderate	1.5–5	10–20
High	5–25	20–30

A second group of authors link the swelling rate and/or shrinkage to two parameters (Djedid et al., 2001). A first classification is based on the plasticity index and the fine clayey fraction. The second method suggests the use of the liquid limit method and the percentage of fine particles whose diameter is less than 74 µm. In this case, the studied material which has a plasticity index more than 18% (21%) and a fine clay fraction of 18%, and a liquid limit of 54%, is classified among soils whose swelling is high (Table 6), although contrary results are revealed by the mineralogy and the CBR. In fact, the method of evaluation of swelling rate based on ås calculation seems to be in accordance with mineralogical and CBR results.

Table 5. CBR values of crushed gneiss (0/31.5) with lateritic gravels mixtures

20 wt.% of 0/20 80 wt.% of lateritic gravels	25 wt.% of 0/20 75 wt.% of lateritic gravels	30 wt.% of 0/20 70 % wt.% of lateritic gravels	20 wt.% of 5/20 80 wt.% of lateritic gravels	25 wt.% of 5/20 75 wt.% of lateritic gravels
49	54	69	92	104

Table 6: Swelling potential of soils according to their plasticity index, liquid limit and respectively their <2 and 74 µm fractions

PI (%)	<2 µm	<74 µm	W_L	Swelling potential
>35	>95	>95	>60	Very high
22–35	60–95	60–95	40–60	High
18–22	30–60	30–60	30–40	Moderate
<18	<30	<30	<30	High

Conclusion

The study of the geotechnical, mechanical, chemical and mineralogical properties of lateritic gravels of Boumpial (East Cameroon) reveal three facts.

The sample is mainly constituted of kaolinite (34 wt.%), hematite (24 wt.%), goethite (13 wt.%), quartz (11 wt.%), gibbsite (10 wt.%) and anatase (wt.%) without swelling clay minerals such as smectites.

The silica/sesquioxides ratio turns around 1.04 and the swelling rate is less than 0.1%. The studied lateritic gravels is suitable for sub-base course.

These lateritic gravels can be used for base course if treated physically by mixing with rock fragment of gneiss having a Los Angeles index less than 60%, this requires a proportion of 20 wt.% of the 5/20 fraction and 80 wt.% of raw material.

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