World Journal of Engineering and Technology, 2025, 13(3), 585-606
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Characterization and Valorization of Tailings from BIENKOK (EDEA-Cameroon) Quarry for Reinforcement of the Mechanic Behavior of Roads Base Layers

Joseph Bikoun Mousi[1,2*], Monique Makamyou[1], Rolande Aurelie Tchouateu Kamwa[2,3], Michelle Ndiang[1], Claudia Pamella Manou Oyong[2], Emmanuel Yamb[4], Jacques Etame[1]

[1]Department of Civil Engineering, Higher National Polytechnic School (HNPS), University of Douala, Douala, Cameroon
[2]LASOGEMA Laboratory, Department of Civil Engineering, University Institute of Technology (IUT), University of Douala, Douala, Cameroon
[3]Department of Chemistry, Faculty of Sciences, University of Douala, Douala, Cameroon
[4]Department of Civil Engineering, ENSET, University of Douala, Douala, Cameroon
Email: *josephbikoun@gmail.com

How to cite this paper: Mousi, J.B., Makamyou, M., Kamwa, R.A.T., Ndiang, M., Oyong, C.P.M., Yamb, E. and Etame, J. (2025) Characterization and Valorization of Tailings from BIENKOK (EDEA-Cameroon) Quarry for Reinforcement of the Mechanic Behavior of Roads Base Layers. *World Journal of Engineering and Technology*, **13**, 585-606.
https://doi.org/10.4236/wjet.2025.133038

Received: May 8, 2025
Accepted: August 15, 2025
Published: August 18, 2025

Abstract

This work concerns the ecological management of tailings which is BIENKOK mining waste that affects the surrounding vegetation. The quarry, located in the coastal region of Cameroon and more precisely in the Dibamba district at BIENKOK coordinates 3˚57'40" north and 10˚08'37" east, used to produce approximately 18,000 tons of tailings each year. This article aims to reuse these residues in road construction projects. An initial geological and mineralogical study indicates that the rock is an orthogneiss rich in amphiboles and pyroxene classified as R6. Geotechnical studies were also been conducted to characterize the material. The results of the mechanical parameters of the rock, namely the Los Angeles coefficient (27%) and the Micro Deval coefficient (11.2%), enter defined spindles by referenced standards. The bearing capacity using the CBR method, gives an index of 104.5. The state parameters indicate a permeable material ($10^{-4} \leq k \leq 10^{-5}$ m/s) and very slightly compressible ($C_c = 0.162 < 0.2$). The physical parameters (specific density, bulk density, particle grading, Atterberg limits and methylene blue value), fit into the range demanded for the construction of the sub base and base pavement layer of low to medium road classes. Furthermore, the tailing material meets all the requirements related to the use of GNT, listed in pavement design guides (LCPC and CEBTP). This has allowed the material to be classified as GTR, class B31. The tailing materials are therefore useable in the composition of pavement structures and embankments. Its usefulness in the construction of unpaved roads as a wearing course for the roads and routes of the mining sites also appears promising, not only for the rolling stock but also for environmental and economic efficiency of the mining exploitation.

Keywords

Tailing Material, Road Construction, Bearing Capacity, Waste Reduction, Quarries Exploitation

1. Introduction

The production of industrial waste is a common environmental problem encountered by many companies on their sites. When the environmental impact is severe, the project may be cancelled by organizations that advocate for the sustainable development goals. In the case of mining and quarrying in particular, this issue is no exception. In 2008, more than 250 million tons of rock were produced in Canada only [1]. These residues are disposed of in dumps, because they do not have a considerable economic value and, nevertheless, occupy a fairly large area and could affect vegetation.

In the quarry located at BIENKOK (Edéa-Cameroon), where a hard rock massif is exploited, each ton of aggregate produces about 5 % of tailings material and one can observe: natural disorder, lack of storage space, vegetation destruction, risk of falling and rockfall. The development of these tailings appears therefore as a solution to the environmental problems it causes. The reuse of these materials for the construction of dams or inclusions of rock in tailings ponds [2], in underground mine site backfill [3], in overburden during site restoration [4] and in mining transport roads [5] are examples of the direct recovery of these materials at mine sites. It is both economically and environmentally desirable to reuse the waste rock since it is available directly on site and its use reduces the volume of stored material. More particularly, mining transport roads need to be built strongly in order to facilitate customers' access and transport of materials, thus increasing the productivity and reliability of quarries. As a result, seeking a proper method to improve the bearing ability of earth soils is still of interest. According to Joseph Bikoun Mousi *et al.* (2024), the tropical zone encompasses the majority of Sub-Saharan Africa and is almost covered by lateritic soils. For instance, in Cameroon, the lateritic soil covers around 70% of the country area [6]. Its coastal side is characterized by the highly rainfall season. This induces the presence of earth soils having a high proportion of fine and clayey fractions. This very often makes these soils unstable and therefore problematic for road works. Furthermore, roads in quarries area are often been used by highly loaded vehicles. They therefore need to be strong enough in order to increase the business income by reducing transport duration. On the other hand, quarries like BIENKOK produce many tailings, which in this case, is been abandoned in the environment with a severe negative impact on vegetation. It is therefore important to reuse the locally produced tailings to increase the load bearing capacity of its servitude roads (inside the mining and from the mining site to major roads). Note that the complete absence of a structural and functional designed road presents the least expensive option initially. Nevertheless, the cost for vehicles maintenance increases when the road structure has not been optimally designed and the material of the running surface has not been well chosen [5]. This results in more defective roads. Defective roads have an impact on both the driving comfort, security and productivity, as well as vehicle maintenance. This will therefore lead to a lower productivity of the mining site [5].

Several investigations have been devoted for soils stabilization using hydraulic and hydrocarbon binders, such as cement, lime, bitumen, etc. [7]. Earlier, Mengue *et al.* [8] designed a pavement foundation layer from fine-grained lateritic soils treated with cement at different dosages (3%, 6% and 9% of soil dry weight). They reported that the use of cement treated fine-grained lateritic soil can significantly reduce the thickness of the pavement layer, while ensuring required features like resilient modulus MR, modulus of elasticity E, layer coefficient and structural number SN [9]. Among techniques used for the improvement of the bearing capacity of such roads, the road design standard for roads in tropical countries (CEBTP) proposes the use of untreated well graded gravels with particle sizes varying between 0 mm and 31.5 mm [7]. A CBR value greater than 80 is expected from this material, for its use on the base course layer of low to medium road classes [10]. The results reveal the efficiency of gravel materials for the construction of road pavement layers [11]. The CEBTP design standard prescribes a minimum CBR value of 60 for the sub base layer of medium road classes [7]. Therefore, with good geotechnical, mineralogical and mechanical results on the studied tailings, this material could be used to construct sub base and base layers of low to medium road classes.

The main objective of this work is therefore to contribute to the preservation of the close environment of the quarry by reusing the tailings it produces for the development of its circulation roads. A method for reinforcing or stabilizing sub-base and base pavement layers of servitudes leading to the BIENKOK quarry, with tailings from the quarry. BIENKOK tailings are therefore been classified according to current and standardized methods [12]. Its geotechnical characteristics are then been compared with similar products such as the crushing material still called untreated grave [13]. The final contribution is to justify the possible uses of tailings in road works where untreated gravels (GNT) intervene through an analysis of the behavior of tailings once it is been implemented [14].

2. Materials and Methods

2.1. Materials

The main material used in this work is the tailings from the stone quarry located at BIENKOK, EDEA-Cameroon (**Figure 1(a)**). The samples of this material were taken from the tailings stock in place at the quarry (**Figure 1(b)**).

Figure 1. BIENKOK tailings sample (a: tailings material, b: quarry and tailings on vegetation).

Sampling was carried out on different stocks, at different points and on several levels in accordance with standard EN 932-1 (**Figure 2**) [15]. Sampling is done to make sure the studied sample in the laboratory is representative of the tailing stock pile [16].

Figure 2. Sampling at the stockpile.

Figure 3. Sampling at the laboratory using a sampler.

Samples are taken from various wells around the stockpile. Before sampling, the top is scrapped to a depth of at least 30 cm. The well material is then thoroughly mixed on the stockpile before being collected in bags [15]. Once in the laboratory, the materials are dried and the five pits are being thoroughly mixed. Using a sampler, the sample for each test is taken after quartering (**Figure 3**).

A sample of the solid was also taken from the cutting front for analysis of thin blades.

2.2. Mineralogic Identification

This identification was done using polarizing microscope for the microscopic observation of the rock sample.

2.3. Geotechnical Identification

In order to characterize the material, many laboratories equipment have been used.

2.3.1. Particle Size Analysis

Particle size analysis is widely described as the process in which dry, free-flowing material is analyzed to determine the grain size ratio of the material. The material used for this involves a screen column of the series ϕ315 H77 for separating the grains from the sample; then an electric sieve which facilitates the vibration of the screen as shown in **Figure 4(a)**. It was also used an electronic scale for weighing (**Figure 4(b)**), a drying oven, and finally bowls for the retention of samples [17].

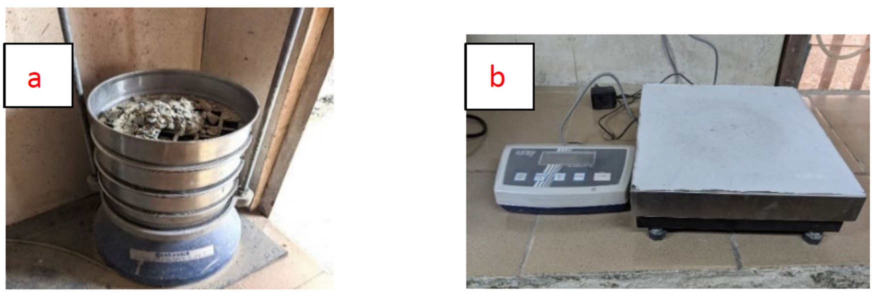


Figure 4. (a): sieves column; (b): electronical scale.

After quartering, dry or wet material is been placed in a tray. The material was then been washed on a 0.08 mm sieve by continuous water change [13]. The 0.08 sieve reject is been dried at 105˚C for 24 hours and poured into a sieve column. The sieve column is shaken using a shaking table and the refusals of each sieve is cumulatively weighed according to the NF EN 933-1 standard [18]. Once the test sheet is filled, the grain curve is been plotted and interpreted.

2.3.2. The Flattening Coefficient

In addition to the particle size analysis, the flattening coefficient test is used to characterize the more or less massive form of aggregates. Equipment used a set of 12 different spacing slit grids. The flattening coefficient test (ASTM D 4791 standard) of aggregate is used to characterize the form of aggregates whose size is between 4 and 40 mm and to monitor the regularity of gravel supplies during the construction project. A rubble unfavorable shape (flat or elongated) has a high flattening coefficient (20% to 40%). A rubble favorable shape (spherical, cubic or nodular) has a flattening coefficient generally less than 20%. Three main dimensions define the form of aggregate: the length, the thickness and the coarseness. The lower the flattening coefficient is, the lower the angularity and the percentage of flat and elongated particles will be [19].

After passing the aggregate through conventional flattening sieves, the different granular classes were isolated and then sieved one by one on parallel slot grids. Thus, each granular class d/D can be associated with a corresponding slot sieve. This allows partial flattening coefficients to be defined. It was then possible to determine the overall flattening coefficient following NF EN 933-3 standard [20].

2.3.3. Sand Equivalent Test

Sand equivalent test is a rapid field test used to show the relative proportions of fine dust in the sandy or granular aggregate. According to NF EN 933-8 requirements, the equipment presented in **Figure 5** has been used to determine the cleanliness of the sand (0/2 mm portion) such as: Plexiglas test pieces; a funnel; a 5-litre canister containing the washing solution; a metal washer tube; a device for shaking the test pieces; a metal rod and a tared piston [21].

Figure 5. Sand equivalent apparats (a and b).

The test is used to assess the cleanliness of sands following NF EN 933-8 standard [21]. The test tube was filled with washing solution until the first line marked 100 mm. A defined mass of material ($D \leq 4.75$ mm) is then been poured the solution. The cylinder is then been agitated to loosen fine like particles coated on coarse particles. Irrigating the sample with additional flocculation solution will force the finest particles move above the sand. Thus, after the sedimentation period, the height of flocculated particles (H_1) and height of sediment particles (H_2) are been measured. The sand equivalent value is then been calculated with Equation (1).

$$\text{ESV} = \frac{H_2}{H_1} * 100 \quad (1)$$

2.3.4. The Methylene Blue Value

The methylene blue value is a function of the amount and characteristics of clay minerals present in the test specimen. This test has required the use of a solution of methylene blue carefully stored in amber glass. A fine agitator allows the solution to be dispensed into the beaker containing the material. With the glass rod, the sample can be taken and placed on the filter paper.

100 g of the test sample ($D \leq 2$ mm) is been put it in a 3000 cm^3 container, suspended in 500 cm^3 of demineralized water. Using the dosing device, we introduced into the suspension maintained in constant agitation at 400 r/min, 5 to 10 cm^3 of blue solution depending on the estimated clay content of the material. The value on methylene blue (VBS) is determined following NF EN 933-9 standard requirements [22].

2.3.5. Specific Gravity

The test material to determine the specific unit weight of the sample is constituted of a wide-necked graduated pycnometers, a scale, a water tank and a graduated thermometer. The test is done according to the NF EN 1097-6 standard [23]. The dry mass of the soil (M_s) and the specific volume of the particles V_s, (the volume of voids been removed), the soil absolute unit weight is calculated with Equation (2).

$$\rho_s = \frac{M_s}{V_s} \tag{2}$$

2.3.6. The Bulk Density

Depending on the size of the largest diameter of the sample to be analyzed, the bulk density is been determined with cylindrical containers of 1 l, 5 l, 10 l or 20 l (**Figure 6**). This test consisted of pouring the aggregate into a cylindrical container of known volume (V), weighing it to obtain the apparent mass of the soil (M). The bulk density is been determined according to NF EN 1097-3 standard, with Equation (3) [24].

$$\gamma = \frac{M}{V} \tag{3}$$

Figure 6. Cylindrical container.

2.3.7. Atterberg Limits

Equipment used for Atterberg limits finding is presented by **Figure 7**. Casagrande couple is used to determine the liquid limit and the marble plates to roll the plastic limit.

Figure 7. Equipment for Atterberg limits.

The water contents that delimit the four states of consistency are called consistency limits or Atterberg limits. The plastic limit (LP) is defined as the water content of a soil that has lost its plasticity and cracks by warping when subjected to low loads. It is the water content at which the rolled soil into a thread will break at a diameter of 3.2 mm This boundary separates the plastic state from the semi solid state. On the other hand, the liquidity limit (LL) is the water content that separates the liquid state from the plastic state. At this water content, the soil will no longer flow like a liquid. It is been determined as the water content at which the soil in the Casagrade coupel will flow down to close the opened 1cm lips, after 25 blows. Plasticity and liquidity limits are used to identify and classify fine-grained soils following the NF P 94- 051 standard [25]. Then the plasticity index (I_p) can be calculated with Equation (4).

$$I_p = w_l - w_p \tag{4}$$

2.3.8. Oedometer Compressibility and Permeability Test

The oedometer press was used to determine the permeability of the soil. The material consists of a frame, a piston and a water drain tube (**Figure 8**).

Figure 8. Oedometer press.

The test consists of measuring the height variation as a function of time in the stressed soil sample σ. After 24 h, primary consolidation was considered complete. A second load was then carried out on the same sample with a stress usually twice as high as the previous stress, and so on. For a given loading stress, the settlement (Δh) versus time curve is been plotted. In addition to this, for 24 hours of each loading, the total settlement versus applied stress (consolidation) curve is been plotted on a semi-logarithm axis. From these curves, the consolidation coefficient C_v (m^2/s) can be evaluated, which allows the time of compaction of a soil layer in place under any load to be calculated using the Equation 5.

$$t = \frac{T_v \times h^2 D}{C_v} \tag{5}$$

A compressibility curve in the form $e = f(\log\sigma')$, where e is the voids index corresponding to the final settlements measured at the end of each loading step under a stress σ The void index variation equivalent to the variation of the soil height h; $\Delta h/h_0 = \Delta e/(1 + e_0)$. From this curve we can determine: the pre-consolidation stress Δ'_p (the highest stress to which the soil has been subjected in its lifetime), the compression index C_c (Equation (6)) and the swelling index C_s. The tests were been conducted following NF EN ISO 17892-5 standard [26].

$$C_c = \left| \frac{\Delta e}{\Delta(\log \sigma')} \right| \tag{6}$$

Permeability has been obtained according NF X30 - 441 standard, using the DARCY law in the case of laminar flow, with Equation (7).

$$v = k \times i \tag{7}$$

v: average velocity; i: hydraulic gradient; k: permeability in m/s.

2.3.9. Los Angeles Test

The Los Angeles test is used to measure the resistance of a sample of aggregate to fragmentation by impact. It consists of measuring the quantity of elements below 1.6 mm produced by subjecting to shocks of standard steel balls (**Figure 9(b)**) used as abrasive charge in the machine of Los Angeles (**Figure 9(a)**), according to NF EN 1097-2 requirements [27]. The test aids to test the hardness property of aggregates. It gives the percentage wear due to relative rubbing action between the aggregate and steel balls.

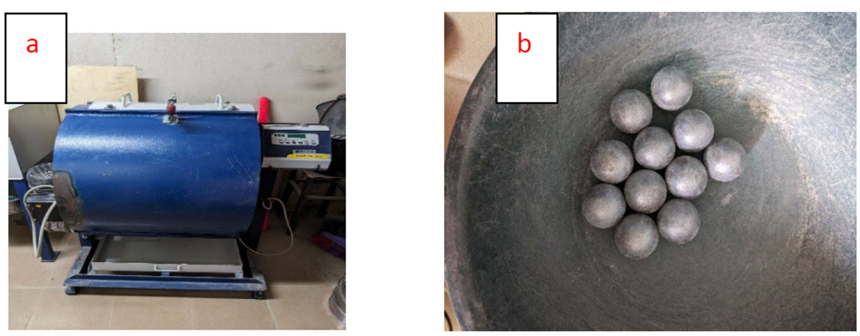


Figure 9. (a) Los Angeles machine, (b) spherical balls.

2.3.10. Micro-Deval Test

Having almost the same features as the previous test, here we used the Micro-Deval machine that is made of several metal jars that contain spherical steel balls with standardized masses and in the presence of water. The test consists in measuring the wear of the aggregate produced by mutual friction in a rotating cylinder under well-defined conditions following NF EN 1097-1 standard [28].

2.3.11. Proctor Test

Proctor test enables to determine the soil optimum water content at which when compacted with a defined energy, the soil will attain its maximum dry unit weight. For this test, we needed Proctor molds (**Figure 10**) and boards. In addition, other small equipment was needed such as: the top, the base, the disc, a balance and a graduated test tube for measuring water quantities.

Soil optimum load bearing is at maximum dry density. Soil compaction reduces air void content and grains are brought near each other to provide mechanical interlocking. This depends on water content, soil type, energy and technique used. Proctor test is used to determine the relationship between water content and dry density of the material given a particular amount of compaction energy. It allows an estimate of the optimum water content at which maximum dry density can be achieved on construction sites and provides reference parameters for assessing the density of the compacted layer.

The modified Proctor compaction test is been done using a cylindrical CBR mould with its corresponding compaction hammer. The mould is been weighed without its top and bottom (m_m) and its volume measured (V_{tot}). With the sampling machine, five samples of 6000 g of well-distributed soil are measured. Each sample is then well mixed and wetted with a percentage water weight, chosen such that after three-percentage water content steps, the optimum water content should be crossed. The wetted soil, after been mixed homogenously, is been covered during the compaction to avoid rapid water evaporation.

Figure 10. Proctor mold.

The test consists of compacting five soil layers the mould, at 56 blows per layer. The mould with the soil is weighed (m_{m+s}) and its water content been determined (Equation (8)). The water content against dry unit weight is been plotted, from which the maximum dry unit weight at the top of the curve is read with its corresponding water content (optimum water content) [29].

$$\gamma = \frac{m_{m+s} - m_m}{V_m}$$

$$\gamma_{dry} = \frac{W_{solid}}{V_{tot}} = \frac{\gamma}{1+w} \quad (8)$$

2.3.12. California Bearing Ratio (CBR) Test (NF P94-078)

The California bearing ratio (CBR) is a measure of the strength of the material to be used in the construction of a pavement layer. The main material here was the CBR press (**Figure 11**), which was been used for punching the compacted soil in a CBR mold [18]. The bearing capacity of soils is related to the resistance to excessive deformation. It can be determined with the CBR test, a standardized penetration test in which a piston (diameter 50 ± 0.5 mm) penetrates soil specimen (compacted at 90%, 95% and 100% of the maximum density) at a fixed rate (rate of 1.27 ± 0.20 mm/min). As deformation occurs, penetration to failure is observed, recording the force causing it. The CBR value is expressed as a percentage of a standard load at fixed penetration depths of 2.5 mm ($I_{2.5}$) and 5 mm ($I_{5.0}$) with a correction coefficient from the press calibration ($\propto = 0.22$). When immerged in water for 96 hrs (**Figure 11(a)**) the procedure includes the measure of vertical swelling (**Figure 11(b)**) of the surcharged, immerged test piece. The standard penetration test (**Figure 11(c)**) is been done on the test pieces, after drainage of excess water for 2 - 3 hours [30].

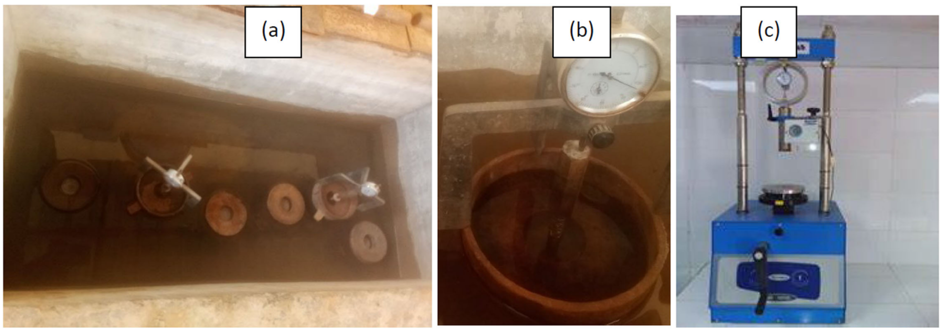


Figure 11. CBR press: (a) immersion of surcharged test pieces for 96 hrs, (b) measurement of vertical swelling, (c) standard penetration test.

The CBR value is computed by dividing the recorded load (at 2.5 and 5 mm penetration depths) by the relative standard load of a high quality crushed-stone material (Equation (9)).

$$I_{\text{CBR 25}} = \frac{\text{Penetration effort at 2.5 mm sinking}(\text{KN})}{13.35\ \text{KN}} \times 100$$

$$I_{\text{CBR 50}} = \frac{\text{Penetration effort at 5 mm sinking}(\text{KN})}{20\ \text{KN}} \times 100 \quad (9)$$

2.4. Data Processing Equipment

All data collected from the laboratory tests were processed by Word and Excel

2019 software for calculations, curves, diagrams and tables using a personal computer i3, 16Go and 3 GHz with Windows 10 pro-operating system.

A mobile phone was used for taking photos and the Garmin 64 s GPS for taking geographic coordinates.

2.5. Sampling Method

The material was collected on field using a shovel, wheelbarrow and plastic bags. The standard method of sampling was used at different points (NF P 932-1), at different heights or depths throughout the stock [15]. The stock could have undergone segregation when put in place. A sampling heap is been used to thoroughly mix up the stock. A hand-held shovel is then been used to take a number of samples from random locations in the pile.

All samples were homogenized by laboratory quartering according to EN 932-2 [31] and divided into several containers of between 20 and 30 kg. The granulometric curves of several samples after separation were analyzed to ensure the quality of homogenization. Each sample tested in this project was therefore representative of the material sampled in the field.

3. Results and Discussion

3.1. Results of Geological and Mineralogical Analysis

Geological and mineralogical analysis on a thin-plate microscope (**Figure 12**) shows the rock has a hetero cellular granoblastic texture consisting of potassium feldspar, quartz, pyroxene and plagioclase minerals. The accessory phase is represented by opaque minerals such as magnetite, titanium and hematite.

Potassium feldspar is the most abundant mineral in rock, with a percentage ranging between 45% and 55%. It is sometimes represented in the rock by the orthese. Potassium feldspar is a sub-automorphic and xenomorphic crystal of size varying up to 1.5 mm long for the largest and 0.2 mm long-axis for the smallest. The phenocrystals are essentially fractured and some fractures are filled with a quartzo-feldspar liquid. The association of orthose and quartz is frequent.

Quartz (30% - 35%) is in the form of polycrystalline solid materials (solid materials made up of a multitude of small crystals of varied orientation). These small crystals are been rolled extinguishing and their size does not exceed 0.5 mm. In places, these small crystals clog the fractures of large crystals. Some quartz crystals form boundary granulation of potassium feldspar and pyroxene porphyroblasts.

Plagioclase (<10%) is scattered in the rock. It is represented in the rock by small crystals that associate with those of quartz and potassium feldspar to form the frame of the rock.

Pyroxene (3% - 5%) is represented by the clino-pyroxene. The latter, constitutes the only ferromagnetic mineral phase of the rock. It is essentially xenomorphic. Their sizes are variable between 0.3 and 2 mm in the long axis. All pyroxene crystals contain quartz and potassium feldspar inclusions. There is also a major transformation of pyroxene crystals into opaque minerals.

Opaque minerals (1% - 3%) such as magnetite, titanium, hematite and crichtonite are xenomorphs of millimeter size. They are mainly derived from the transformation of pyroxene.

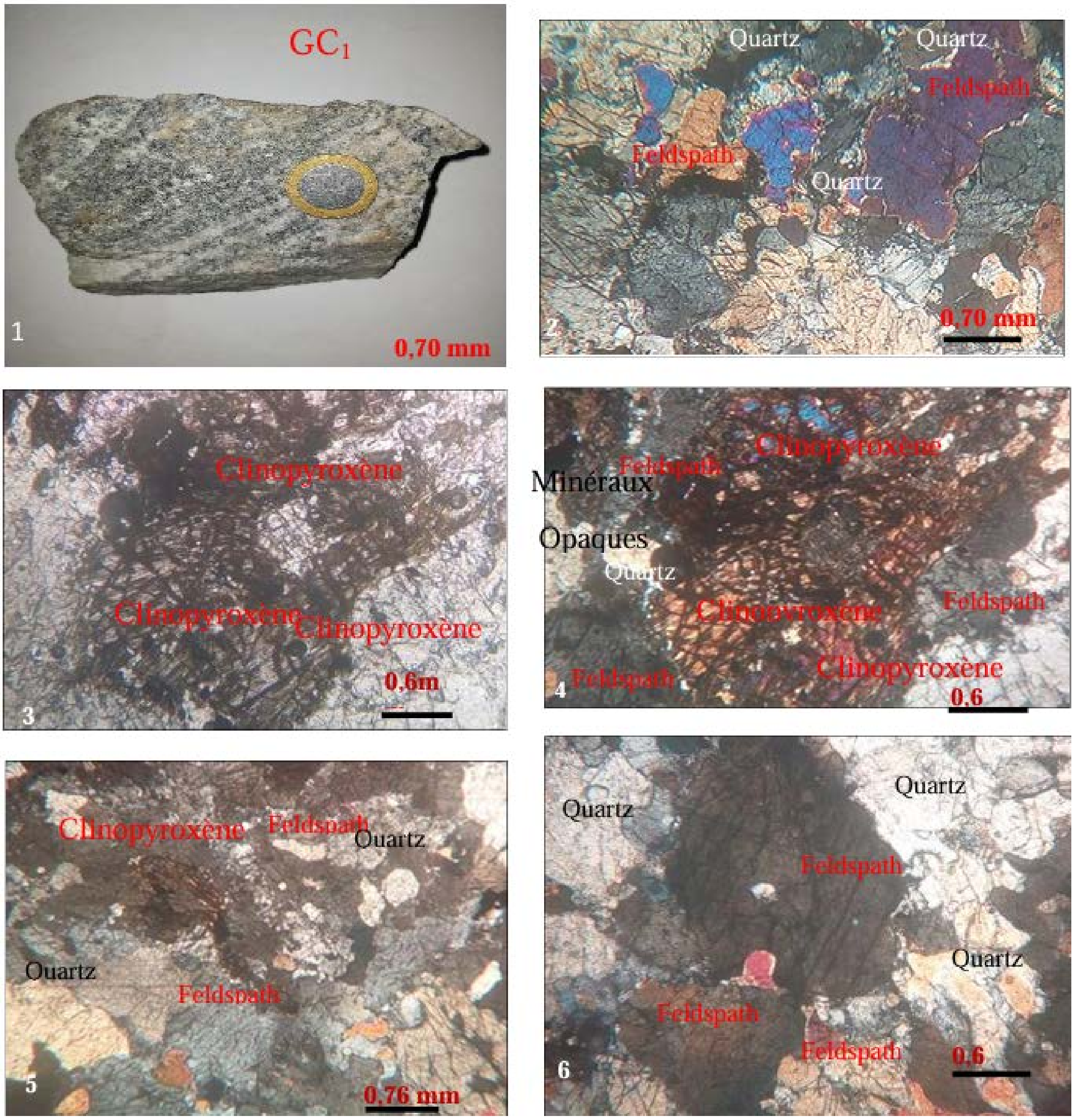


Figure 12. LPA analysis of a thin blade (Presence of potassium, quartz, felspar, pyroxene and plagioclase).

The petrographic analysis of the rock from the EDEA quarry has shown foliations and schistosity, and mineralogically a quartzoid - feldspathic bath with pyroxenes and ferromagnetic is been observed. The exploited massif is therefore a pyroxene orthogneiss. This result is similar to the geological recognition of rocks in the EDEA region done by OSTORM. According to the GTR classification, we are in the presence of a rocky material of type R6 [32].

3.2. Results of Geotechnical Tests

As seen in Figure 13, the 03 samples analyzed gave curves in accordance with the specification of untreated gravel (GTR), and fit fully into the standards [32]. The particle size grading of the tailings is continuous and favorable for use on the sub base and base pavement layers.

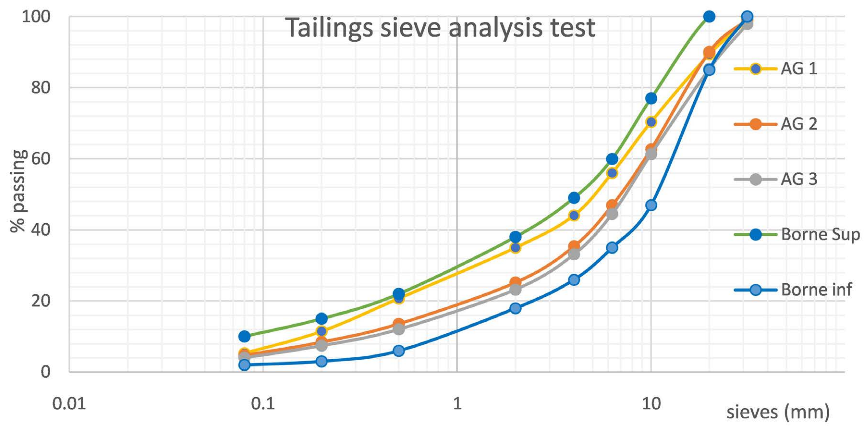


Figure 13. Sieve analysis curves of samples of tailings.

Figure 14 shows the different flattening coefficients (FC) of the three studied samples, obtained during the characterization.

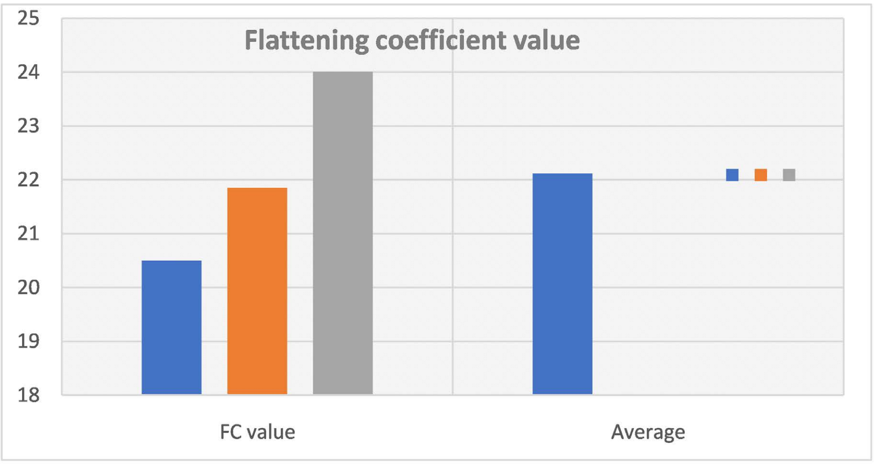


Figure 14. Diagram of flatness coefficient value.

The average flattening coefficient of our samples gave 22.11%. It is not a required parameter for the use of untreated graves for foundation and base layers. However, the shape of the grains greatly influences compaction of a fill material.

Sand equivalent test gave an average of 61.7% for our sample as seen in Table 1 below.

When the sand equivalent has a value more than 60% as it is the case for our tailings, a blue analysis is necessary to determine the quality of fine of our sample.

As seen in Table 2, the tailing samples have an average methylene blue absorbed value (MBV) of 23%. With a value varying between 0.2 and 0.25, the tailing material is said to fall in the group of silty soils. According to the classification in the pavement design guide for tropical countries (CEBTP), the Tailings material analyzed is poor in clay and does not present a risk of shrinkage or swelling during use [32].

Table 1. Tailings sand equivalent test.

Date: 27/09/23		Sample: BIENKOK tailings				Granular class: 0/5	
Parameters		Sample	H1	H2	H'2	ESV	ESP
Bulky mass mh (g)	235.3	1	131	80	72	61.07	54.96
Dry mass (g)	225.4	2	130	81	75	62.3080	57.69231
Water content (%)	4.39	Average value				**61.7**	**56.3**
Sample mass (g)	125.27						

Table 2. Methylene Blue Value (MBV) of the tailings.

Methylene Blue Test			
N° sample	1	2	3
Mass of test sample (g)	100	100	100
Blue mass introduced (g)	25	20	25
MBV	0.25	0.2	0.25
Average		0.23	

Table 3. Tailings specific gravity value.

Specific gravity			
N° sample	1	2	3
Mass of material (g)	410.6	566.82	597.8
Volume of material (cm^3)	149.123336	209.08754	223.534374
Specific gravity (g/cm^3)	2.75342554	2.71092196	2.67430906
Averrage (g/cm^3)		2.71	

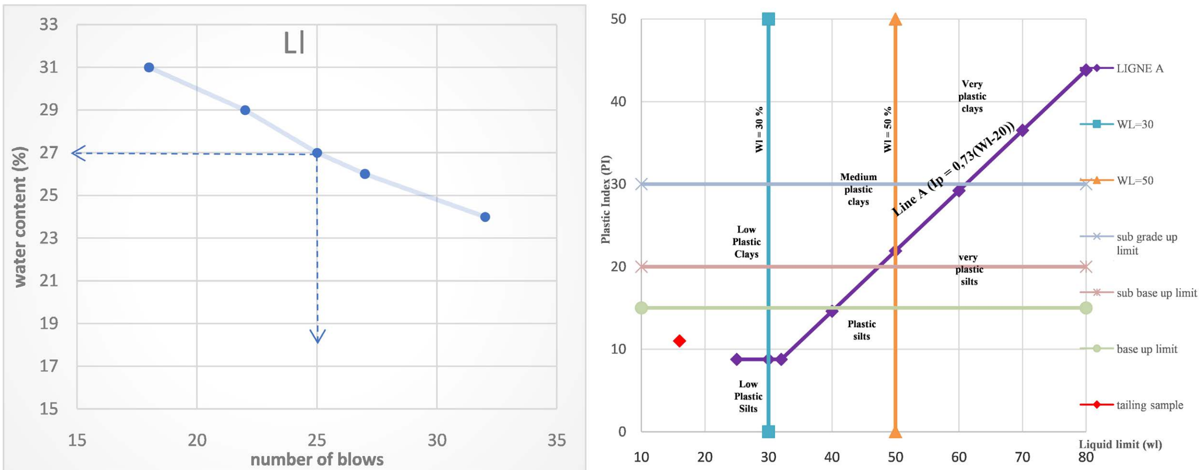
Table 4. Value of the bulk density of the tailing material.

Bulk Density			
N° sample	1	2	3
Mass of material (g)	179.31	181.58	180.88
volume of the cylinder (cm^3)	102.36	102.36	102.36
Specific Gravity (g/cm^3)	1.7517585	1.77393513	1.76709652
Averrage (g/cm^3)		1.76	

The value of the specific gravity is based on the density of the minerals which can be light, common or heavy (Table 3). The specific unit weight of our sample is 2.71 g/cm³. The specific unit weight of the tailing material falls between 2 and 3. It is therefore a common material.

The average result obtained on the three tested samples gave a value of 1.76 (g/cm³) (Table 4).

The analysis of soil consistency has yielded a liquid limit of 16% (Figure 15(a)), plastic limit of 27% and a plastic index of 11%. As seen in Figure 15(b), the material is been confirmed on the Casagrande classification chart to be a low plastic silty material.



(a) (b)

Figure 15. Liquid limit and material consistency nature in the Casagrande diagram.

The hydraulic permeability *k* varies between 10^{-4} m/s and 10^{-5} m/s (according to test results) and the tailings is very little compressible, $C_c = 0.162 < 0.2$.

The Los Angeles coefficient characterizing the impact resistance of aggregates gave a value of 27 as showed in Table 5. Its assessment is based on the specific technical clauses of each contract and is generally required by the pavement design guide for tropical countries to be less than 45 for the base layer of T3 roads [32] [33].

Table 5. Los Angeles Coefficient value for tailings.

Los Angeles Coefficient								
Granular Class:	16/31.5	Verification of fractions	Nber of balls	Nber of rotations	Sample Mass (g)	Refusal Mass (g) at 1.6 mm	Los Angeles Coefficient: LA	Average
Test 1						3579	28.42	
Test 2		60% of 16/25	11	500	5000	3688	26.24	27.05
Test 3						3675	26.50	

The Micro-Deval coefficient of the tailings gives us the value 11.2%. However, the standard generally recommends a value below 15% for use of the base layer gravel (Table 6).

Table 6. Tailings coefficient MDE value.

MICRO DEVAL Coefficient						
Granular class: 10/14	**Abrasive load**	**Number of rotations**	**Sample mass (g)**	**Refusal mass on 1.6 mm sieve (g)**	**Micro Deval coefficient (MDE)**	**Average**
Sample 1				441	11.8	
Sample 2	5 kg	12000	500	445	11	**11.2**
Sample 3				446	10.8	

Physical identification results obtained allowed us to classify our material according to the GTR (Table 7).

Table 7. GTR classification of BIENKOK tailings.

Nature parameter 1st classification level	Class	Nature parameter 2nd classification level	Sub class	Mechanical behavior parameter	Sub class
Dmax ≤ 50 and passing at 80 mm≤35%	B	Passing at 80 µm ≤ 12%	B3	LA ≤ 45	B31
	Sandy and graveled soil with fines	Passing at 2 mm ≤ 70%			
		0.1 < VBS ≤ 0.2	Severe Silting	MDE ≤ 45	
		ES ≥ 25			

BIENKOK tailings is a class B soil and subclass B31; it is water-insensitive and easily erodes under the action of runoff. It can pose problems of traffic if its granulometry is uniform and if it is dry. It can be used in fill with a medium compaction if the weather conditions are suitable. In case of heavy rain, it is totally been forbidden.

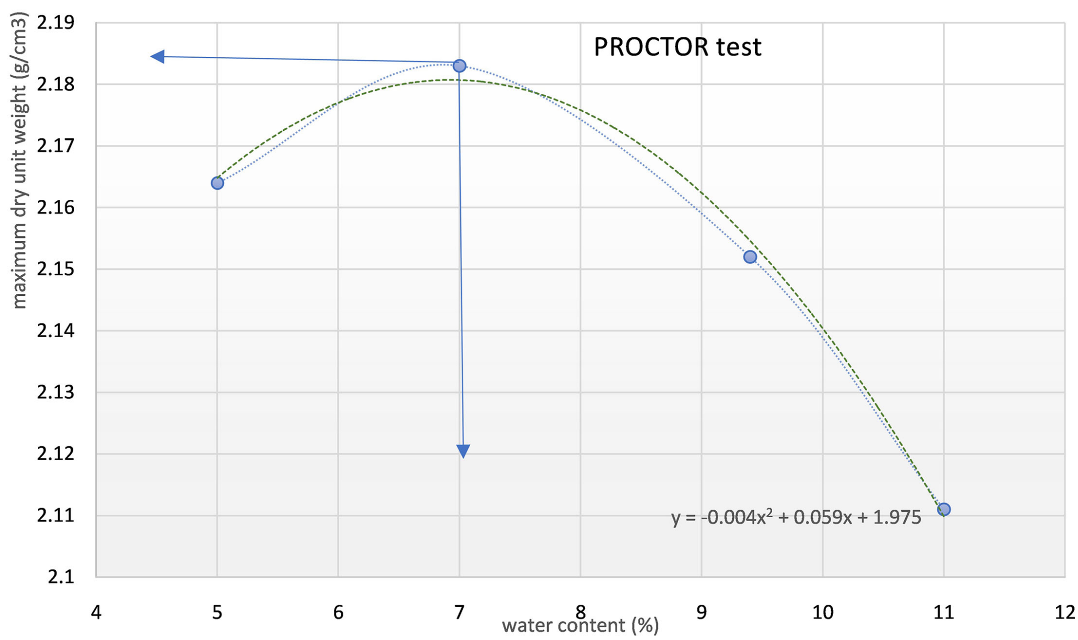


Figure 16. PROCTOR test on the tailing.

The optimum water content 7% and maximum dry unit density (2.186) at the modified Proctor optimum of the tailings are shown in Figure 16 which is very close to Equation curve $y = -0.0043x^2 + 0.0592x + 1.9755$. These values allow to define the conditions to carrying out the CBR test to know the load capacity of our sterile.

California Bearing Ratio (CBR) Test

The results of the CBR test after 4 days of immersion of the tailings of BIENKOK are given in Figure 17. The 95% CBR gave a value of 104.5 [7]. This value enters in the spindle of CBR index values of untreated gravels, and follows very closely the Equation curve $y = -0.0002x^2 + 0.115x + 85.161$. Taking also into account the fact that the minimum recommended value for the base layer of T3 roads is 80, this material is therefore useable for the construction of the named pavement layer.

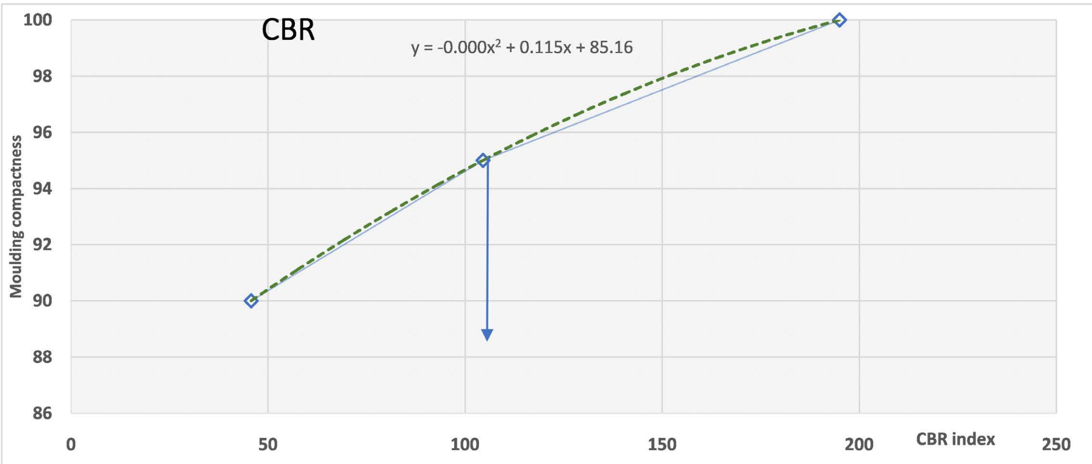


Figure 17. CBR value of the tailing samples.

Table 8. Comparison of results of tailings characterization.

Parameters	Tailings	LCPC	CCTP	Observations
LA	27	≤30	≤35	Conform
MDE	11.2	≤15	≤25	Conform
CBR	104.5	≥80	≥80	Conform
Permeability	4.96E−05	Non specified	Non specified	Permeable material
Compressibility	0.162	Non specified	Non specified	Material not easily compressible
Dmax	31.5	≤60	≤31.5	Conform
% fine	[2 - 10]	Conform		Conform
Particle size distribution	Spindle NF EN 13242	Conform		Conform
ES	61	≤60	≤60	Acceptable based on its VBS value
VBS	0.2	Non specified	≤0.2	Conform
IP	0	≤6	0	Conform
Swelling number	0.005	Non specified	<0.5	Conform

Comparing the tailings parameters with requirements in road design guides (CEBTP, LCPC and CCTP) [7] [32] [33], one can conclude that the tailing material is usable for the development of pavement layers. The material can be used for road sub base and base pavement layers (**Table 8**) of low and medium road classes.

4. Conclusion

This work sheds light on the use of the tailings from BIENKOK quarry mining to improve the load-bearing capacity of layers or sub-layers for road construction in tropical area. Prior, the tailings were geotechnically characterized, and the compaction data (OPM and CBR) indicate that it can only be used as a subbase and base material for T1 - T3 (medium) traffic. All CCTP, LCPC and CEBTP requirements for that category of traffic are fulfilled by the tailings. Dry density was described and it follows regression curve with Equation $y = -0.0043x^2 + 0.0592x + 1.9755$. According to GTR classification, BIENKOK tailings is a class B soil and subclass B31. Concerning the California Bearing Ratio (CBR), the 95% CBR gave a value of 104.5, which is close to that of severe untreated crushed gravel (GTR). The material is therefore quite strong for roads construction. CBR follows regression curve described by Equation $y = -0.0002x^2 + 0.115x + 85.161$. The proposed tailings at the quarry when sold, cost about 3000 FCFA per ton compared to the uncrushed material, which costs 7500 FCFA per tons. Therefore, for the base layer of low to medium traffic roads, a more precise cost effectiveness will clearly lead to potential benefits. In addition to this, the reuse of this material on road constructions will help protect the environment. The reduction or stoppage of the dumping of this material in nearby vegetation around quarries like BIENKOK quarry, where they are been produced as waste will reduce the pollution of soils in the named vegetation. The use quarry's waste is therefore very important for the protection of the vegetation near the mining. Final long-term studies on the durability of the tailings regarding the fatigue of the stone under crushing and shearing stresses will aid to better conclude on its mechanical properties. For the future, studies into litho-stabilisation of local clayed soils with these tailings will open doors for more possibilities of use of tailings in roads construction for the region.

Acknowledgements

The authors thank LASOGEMA (IUT-Douala-Cameroon) and Civil Engineering Laboratory-HNPS Douala-Cameroon for extending all the facilities to carry out this research.

Author Contributions

Joseph Bikoun Mousi, Monique Makamyou, Rolande Aurelie Tchouateu Kamwa: **Validation, Methodology, Writing—review and editing, Visualization, original draft**; Joseph Bikoun Mousi, Monique Makamyou, Rolande Aurelie Tchouateu Kamwa: **Conceptualization, Methodology, Investigation, Writing—origi-**

nal draft; Rolande Aurelie Tchouateu Kamwa, Michèle Ndiang: **PXRD and FTIR analysis, Validation, Writing—review and editing, Visualization;** Rolande Aurelie Tchouateu Kamwa, Claudia Pamella Manou Oyong: **Physical tests;** Joseph Bikoun Mousi, Monique Makamyou, Michèle Ndiang: **Methodology, Writing review and editing, original draft;** Jacques Etame, Emmanuel Yamb, Joseph Bikoun Mousi: **Resources, Supervision.**

Funding

The authors of manuscript did not receive any funding and grants for this work.

Data Availability

All data generated or analyzed during this study are included in this article.

Ethical Approval

This study does not contain any studies with human participants and/or animals performed by any authors.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

[1] Canada, S. (2013) L'activité humaine et l'environnement. N°16-201-X au cataloque, 123.

[2] Aubertin, J.M. (2015) Revue des meilleures pratiques de restauration des sites d'entreposage de rejets miniers générateurs de DMA. *Symposium* 2015, *ROUNYN-NORANDA sur l'Environnement et les Mines*.

[3] Yang, P. (2016) Investigation of the Geomechanical Behavior of Mine Backfill and Its Interaction with Rock Walls and Barricades. Master's Thesis, École Polytechnique de Montréal.

[4] Larochelle, C. (2018) Utilisation de stériles générateurs d'acide comme couche de bris capillaire dans une couverture avec effets de barrière capillaire. Ph.D. Thesis, École Polytechnique de Montréal.

[5] Tannant, B. (2001) Guidelines for Mine Haul Road Design. Ph.D. Thesis, School of Mining and Petroleum Engineering, University of Alberta.

[6] Mousi, J.B., Kamwa, R.A.T., Nemaleu, J.G.D., Tome, S., Gérard, M., Etoh, M., *et al.* (2024) Improvement of the Bearing Capacity of Lateritic Gravel by a Geopolymer Binder: Road Construction in Tropical Countries. *Innovative Infrastructure Solutions*, **9**, Article No. 242. https://doi.org/10.1007/s41062-024-01575-6

[7] CEBTP (1984) Guide pratique de dimensionnement des chaussées pour les pays tropicaux, la documentation francaise. 155.

[8] Mengue, E., Mroueh, H., Lancelot, L. and Medjo Eko, R. (2018) Design and Parametric Study of a Pavement Foundation Layer Made of Cement-Treated Fine-Grained Lateritic Soil. *Soils and Foundations*, **58**, 666-677. https://doi.org/10.1016/j.sandf.2018.02.025

[9] Kaufman, C. (1977) Design of Surface Mine Haulage Roads—A Manual. Bureau of

Mines, Information Circular 8758, U.S. Department of Interior.

[10] Chérif Aidara, M.L., Ba, M. and Carter, A. (2020) Impact of Intrinsic Properties of Aggregate and Volumetric Properties of Hot Mixture Asphalt (HMA) in the Influence of the Resistance to Rutting. *Open Journal of Civil Engineering*, **10**, 187-194. https://doi.org/10.4236/ojce.2020.103016

[11] SETRA-LCPC (1994) Conception et dimensionnement des structures de chaussée, Guide technique, 260.

[12] Bernard, B. (2015) Conception, Tracé, Dimensionnement et Mise en œœuvre des Routes revêtues et non revêtues. Collection Benton.

[13] Babilotte, J.R.C. and Soulie, C. (2009) FASCICULE 2 Dimensionnement des structures de chaussées neuves et élargissements des voies. Communauté Urbaine Grand Lyon, 9-10.

[14] (1997) NF. P. 18-129, Assise de chaussée. Graves non traitées—Définition. Composition. Classification.

[15] (1996) NF EN 932-1, Méthodes d'échantillonnage Indice de classement.

[16] Cherkaoui Auxane, F.C. (2021) Guide de bonnes pratiques sur les critères de stabilité des remblais Remblayage de carrières à ciel ouvert par des déchets inertes. Ineris, 72.

[17] (1983) NF. P. 18-101, Granulats. Vocabulaire. Définition. Classification.

[18] (1997) NF. P 933-1, Essais pour déterminer les caractéristiques géométriques des granulats 6 partie 1: Détermination de la granularité—Analyse granulométrique par tamisage, Afnor.

[19] Douglas, R.A. (2016) Low-Volume Road Engineering: Design, Construction, and Maintenance. CRC Press.

[20] (2012) NF EN 933-3, Essais pour déterminer les caractéristiques géométriques des granulats. Détermination de la force des granulats—coefficient d'aplatissement.

[21] (2012) NF EN. 933-8, Essais pour déterminer les caractéristiques géométriques des granulats Partie 8—Evaluation des fines—Equivalent de sable, Afnor.

[22] (2013) NF EN 933-9, Essais pour déterminer les caractéristiques géométriques des granulats—partie 9: Qualification des fines—essai au bleu de méthylène, Afnor.

[23] (2014) NF EN 1097-6, Essais pour déterminer les caractéristiques mécaniques et physiques des granulats: Partie 6 détermination de la masse volumique réelle, Afnor.

[24] (1998) NF EN 1097-.3, Essais pour déterminer les caractéristiques physiques et mécaniques des granulats Partie 3 :Méthode pour la détermination de la masse volumique, Afnor.

[25] (1993) NF P 94-051, détermination des limites d'Atterberg: Limite de liquidité à la coupelle—Limite de plasticité au rouleau, Afnor.

[26] (2017) NF EN ISO 17892-5, Essai œdométrique avec chargement par palier, Afnor.

[27] (2010) NF EN 1097-2, Essai pour déterminer les caractéristiques mécaniques et physiques de granulats—Partie 2: Méthodes pour la détermination de la résistance à la fragmentation, Afnor.

[28] (2011) NF EN 1097-1, Essai pour la détermination des caractéristiques mécaniques et physiques des granulats—partie 1: Détermination de la résistance à l'usure (micro-Deval).

[29] (2014) NF P 94-093, Soils: Investigation and Testing—Determination of the Compaction Reference Values of a Soil Type—Standard Proctor Test—Modified Proctor test. AFNOR.

[30] (1997) NF P 94-078, Indice CBR après immersion—Indice CBR immédiat—Indice portant immédiat, Afnor.

[31] (1999) NF EN. 932-2, Méthodes de réduction d'un échantillon de laboratoire.

[32] (2000) LCPC-SETRA, Guide technique Réalisation des remblais et des couches deforme. 211.

[33] LCPC-SETRA (1981) Manuel de conception des chaussées neuves à faible trafic, Direction des routes et de la circulation routière.