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(Research Article)

Mechanical characteristics of Avlamè lateritic gravel improved with granite crushed for its use in road construction in Benin

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Abstract

Lateritic gravels are the most abundant road materials used in pavement foundations. With the scarcity of good quality materials, the recourse to lateritic gravels having weak technical characteristics, like the lateritic quarry of Avlamè Benin, is felt with the high price of stabilizers like cement, other methods must be explored in cooperation in order to reduce the cost of stabilization and, consequently, the cost of road construction and the risks related to the environmental pollution In this respect, it is imperative to determine the technical characteristics of the lateritic gravel of Avlamè improved with granitic crushed stone 0/31.5 for its use in the base course of flexible pavements. Thus, an experimental study on Avlamè lateritic gravel with different percentages of granitic crushed stone was carried out following the normative recommendations in road construction. This characterization allowed to highlight the technical properties of the lateritic gravel improved with granite crushed at different percentages. The results obtained show that the pass rate at 80 µm sieve goes from 27.77% to 10.51%, the plasticity index from 17.67% to 11.33%, the dry density at OMC from 2.17 t/m³ to 2.23 t/m³ and the CBR index at 95% at OMC from 58.00% to 108.67%. These results show that mix 2 (85%GL+15%CG), mix 3 (80%GL+20%CG), mix 4 (75%GL+25%CG), mix 5 (70%GL+30%CG) and mix 6 (65%GL+35%CG) can be used as a base course for flexible pavements in accordance with the normative requirements of the CEBTP revised in 2019 and the Catalogue of AGEROUTE-Senegal.

Keywords: Road materials; Base course; 80 µm sieve pass rate; Plasticity index; Dry density at OMC; 95% CBR index at OMC

1. Introduction

Road construction is a sector in which lateritic gravels are most widely used, either as fill material or as body material for the subgrade [1-5]. Thus, they must be of good quality and have the appropriate performances for a judicious use in road construction. In Benin, as in tropical countries, lateritic gravel quarries with good quality materials are becoming increasingly rare. This is the case of the lateritic gravel quarry identified in Avlamè where the material is available, but with poor technical characteristics. Preliminary studies conducted by Houanou et al [6] concluded that this gravel can only be used as a road base. Hence the need to test alternatives for improving the properties of the said gravel in order to use it rationally in road construction. In this respect, the cement stabilization technique was tested on the material. This study showed that the lateritic gravel of Avlamè cannot be used as a base course for semi-rigid pavements when it is stabilized at more than 6.50% cement content in accordance with the specifications of the CEBTP guide [7] and revised in CEBTP [8] and Houanou et al. [9].

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In view of this mixed result, it becomes imperative to explore the technique of lithostabilization which consists in substituting a part of the lateritic gravel by other aggregates of good characteristics for example granitic crushed, Dolerite crushed, crushed alluvial gravel, crushed dust, basalt crushed and palm shells [4,10–14].

2. Material and methods

2.1. Study materials

In this study, the materials used are lateritic gravel and cement.

2.1.1. Lateritic gravel of Avlamè

The lateritic gravel, the subject of this study, is that from the village of Dèmè in the Avlamè district, commune of Zogbodomey. It is located between 6°56' and 7°08' North latitude, 1°58' and 2°24' East longitude. (See figure 1 below).

This lateritic gravel from Avlamè, according to the results of studies conducted by Houanou et al [6], is suitable only for use as a sub-base. These technical characteristics are given in Table 1.

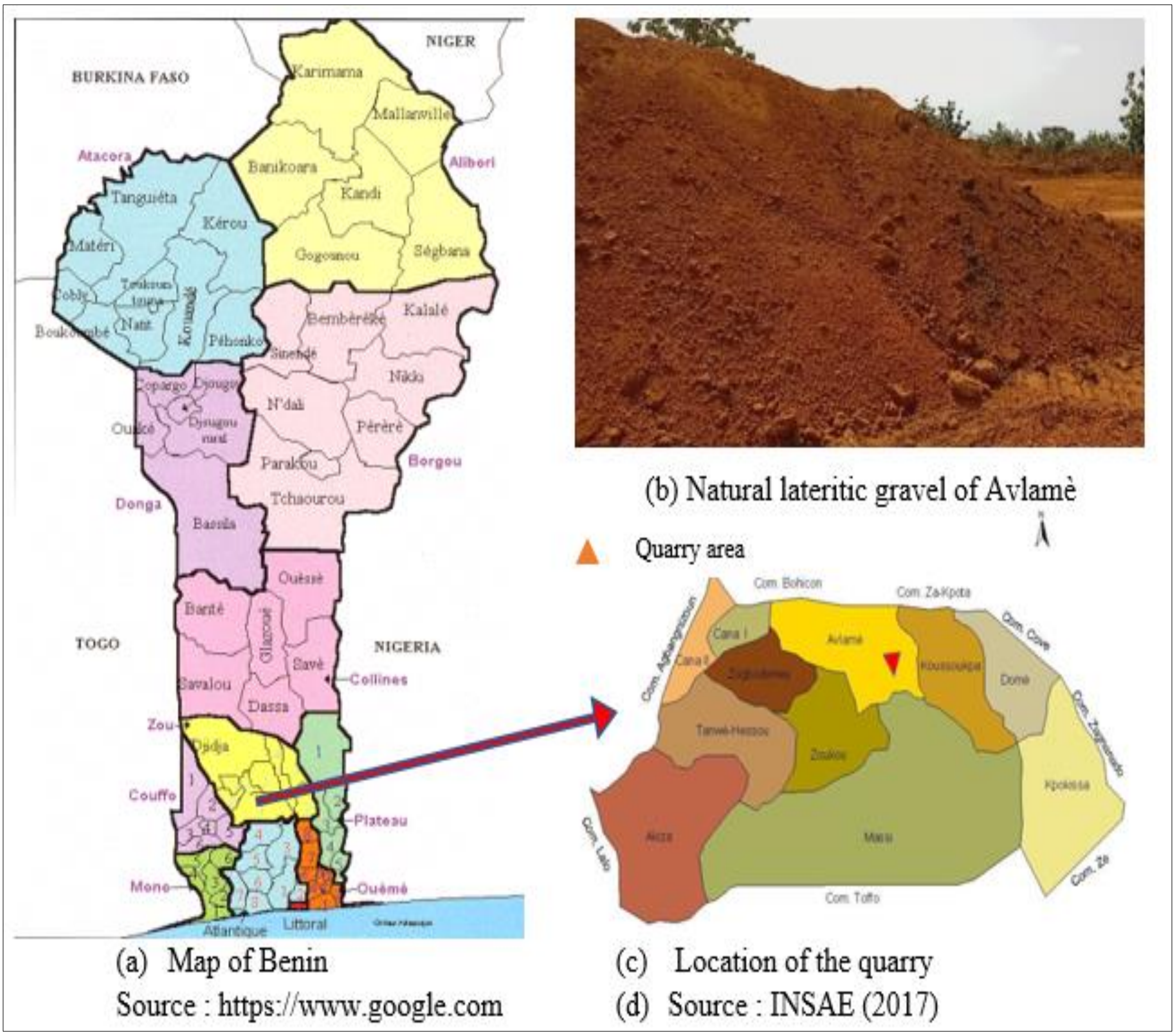

Figure 1 Location of the sampling site

Table 1 Technical characteristics of the lateritic gravel of Avlamè used

Lateritic aggregate		Mean	Standard deviation
Particle size analysis	Dmax (mm)	31.50	0.00
	2mm (%)	35.67	6.03
	0.08mm (%)	27.77	4.04
Atterberg Limits	WL	35.00	1.00
	WP	17.33	0.58
	IP	17.67	0.58
Methylene blue value		0.21	0.02
Organic matter		0.33	0.03
Dry density	γ_d (g/cm^3)	2.20	0.26
Optimum moisture content	ω_{OMC} (%)	7.50	0.30
Maximum dry density	γ_{dmax} (g/cm^3)	2.17	0.17
CBR index after 96h soaking	*95%* OMC	61.00	1.00
	100% OMC	99.33	0.58
Indirecte tensile strength	360 days	0.14	0.00
Directe tensile strength	361 days	0.11	0.00
Simple compressive strength	362 days	1.13	0.09
Secant modulus	363 days	331.71	20.52

Source: Houanou et al. [6]

2.1.2. The granite crusher

The crushing quarry is located in the village of Dan in the commune of Djidja (Zou department) about 30 km from Bohicon (Benin). In this quarry, the crushed materials are screened and piled up by granular class. The crushed material is extracted directly from massive granitic rocks. The crushing technique is artisanal.

Figure 2 Dan granite crusher

2.1.3. The material obtained: lateritic gravel from Avlamè with the addition of granite crushed material

The mixture obtained from the lateritic gravel of Avlamè and the granitic crushed stone of Dan is kept in polyethylene bags in order to prevent the variation of the water content (Figure 3.).

Figure 2 Preparation of mixtures

2.2. Material

The equipment used for the work is classified into two categories depending on whether it is for geotechnical or mechanical testing.

2.2.1. Experimental device for geotechnical tests

The experimental device required for the geotechnical tests on cement-treated lateritic gravel is in accordance with the following standards:

- NF P94-056: 1996 relating to the recognition and the tests on soils: granulometric analysis-Method by dry sieving after washing [15];
- NF P94-050: 1995 relating to the recognition and testing of soils: determination of the water content by weight of materials, method by steaming [16];
- NF P94-051: 1993 relating to the recognition and testing of soils: determination of the limits of Atterberg: limit of liquidity to the cup limit of plasticity to the roller [17];
- XP P 94-047: 1998 relating to the recognition and testing of soils: determination of the weight content of organic matter: method by calcination [18];
- EN 933-8: 2015 relating to tests to determine the geometric characteristics of aggregates. Part 8: Evaluation of fines-Sand equivalence [19];
- NF EN 933-9: 2013 relating to tests to determine the geometric characteristics of aggregates. Part 9: qualification of fines-Methylene blue test [20].

(a) Materials required for the sieve analysis test *(b) Materials for the measurement of the methylene blue value* *(c) Materials for the determination of the Atterberg limit* *(d) Materials for the determination of sand equivalent*

Figure 4 Experimental set-up for geotechnical characterisation

2.2.2. Experimental device for mechanical tests

The experimental device required for the performance of mechanical tests are in accordance with the following standards:

- NF EN 1097-1: 2011 on tests to determine the mechanical and physical characteristics of aggregates. Part 1: determination of wear resistance (Figure 5 (a)) [21];
- NF EN 1097-2: 2020 on tests for determining the mechanical and physical properties of aggregates. Part 2: method for the determination of the resistance to fragmentation (Figure 5 (b)) [22];

- NF P94-093: 1999 relating to the recognition and testing of soils: determination of compaction references of a material: normal Proctor test - Modified Proctor test (Figure 5 (c)) [23];
- NF P94-078: 1997 relating to the recognition and testing of soils: CBR index after immersion - Immediate CBR index - Immediate bearing index (Figure 5 (c, d)) [24].

(a) Materials needed for the Micro-Deval test *(b) Materials needed for the Los Angeles trial* *(c): Molds and checkers for the modified Proctor and CBR test* *(d) : CBR Press*

Figure 5 Experimental device for the determination of mechanical parameters

2.3. Methods

2.3.1. Method of sampling the lateritic gravel

The samples of lateritic gravel were taken according to the standard XP P94-202: 1995 [25], then dried in the open air in the laboratory before carrying out the tests themselves.

2.3.2. Method of formulation

Seven steps are required for the formulation of the lateritic gravel/granitic compacted mixtures. They are listed below:

- Step 1: dry the samples of lateritic gravel and granitic crushed stone in an oven at 50°C for 2 hours or in the air for a suitable time at room temperature.
- Step 2: define the different proportions of granitic crushed stone empirically, for example: 10%, 15%, 20%, 25%, 30% and 35%.
- Step 3: calculate the quantities of each mixture (lateritic gravel and granitic crushed stone) according to the type of test.
- Step 4: determine the water content of each mixture.
- Step 5: determine the water content of each mixture.
- Step 6: mix manually to prevent grain size change in a short time.
- Step 7: package the collected material in airtight plastic bags or self-closing polyethylene bags to maintain a constant moisture content.

2.3.3. Geotechnical testing method

The different geotechnical testing methods are carried out in accordance with the standards cited in § 2.2.1.

2.3.4. Mechanical testing method

The different mechanical tests are carried out in accordance with the standards mentioned in § 2.2.3.

3. Results and discussion

3.1. Characterization test on 0/31.5 granitic crushed stone

The granulometric analysis of the 0/31.5 granitic crushed material allowed to draw the curves of figure 6.

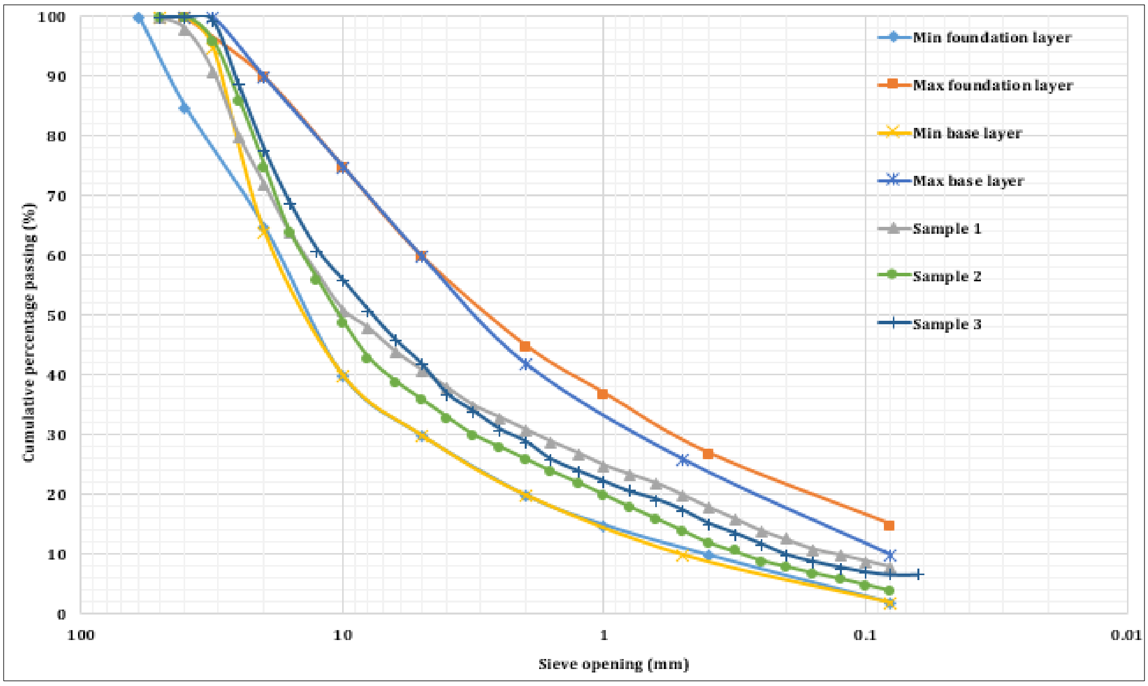

Figure 6 Grain size curve of granitic crushed stone 0/31.5

These grading curves have the same shape and fit well with the normative grading curves of the CEBTP guide [7] and the AGEROUTE-Senegal catalog [26] for untreated gravel 0/31.5.

Table 2 Summary of characterization tests on granitic crushed rock

N°	Particle size analysis			ES	VBS	Modified Proctor		CBR index after 96h of imbibition			MDE	LA
	Dmax (mm)	2mm (%)	0,08mm (%)			ω_{OMC} (%)	γ_{dmax} (g/cm^3)	90% OMC	95% OMC	100% OMC		
Sample 1	31.50	29.00	7.00	57.00	0.70	6.30	2.23	72.00	111.00	164.00	7.00	23.00
Sample 2	31.50	31.00	9.00	56.00	0.78	6.10	2.21	69.00	108.00	155.00	7.00	23.20
Sample 3	31.50	26.00	4.00	59.00	0.73	5.90	2.20	68.00	106.00	149.00	8.00	24.00
Average	31.50	28.67	6.67	57.33	0.74	6.10	2.21	69.67	108.33	156.00	7.33	23.40
Standard deviation	0.00	2.52	2.52	1.53	0.04	0.20	0.02	2.08	2.50	7.55	0.58	0.50

The percentages of refusals at the 2mm and 80 µm sieves of the samples, object of the granulometric analysis, are respectively worth 28.57% (> at least 25%), 7% (< 10%) according to the recommendations of the CEBTP guide [7] relative to the measurement of CBR index.

The sand equivalent test carried out on the 0/31.5 granite crushed the fraction, passing through a 5 mm sieve, showed that it contains 57.33% clean material. Thus, this gravel can be recommended in the construction of roads of traffic T1 to T4 in accordance with the requirements of CEBTP [7].

As for the Los Angeles test, it allowed to obtain a Los Angeles value of 23% lower than the 45% recommended for the T1 -T3 traffic admitting an axle of 8 to 10 tons, on the one hand, and on the other hand, lower than the 30% recommended for the T4-T5 traffic as well as the traffic admitting an axle of 13 tons according to the CEBTP requirements [7].

In the same way, the Micro-Deval test allowed to obtain a value of 7%, lower than 15%, in conformity with the traffic T1 -T3 admitting an axle of 8 to 10 tons, on the one hand, and on the other hand, lower than 12% recommended for the traffic T4-T5 as well as the traffic admitting an axle of 13 tons [7].

Finally, the CBR test determined the CBR index at 95% OPM, i.e., 108%, greater than 100%, compliant for T4, T3 (>80%), T2 (>60%) and T1 (>40%) traffic respectively [7].

These results show that granitic crushed rock is acceptable for use as a base course [26,27]. Therefore, this granitic crushed stone can be used to improve the technical performance of the lateritic gravel of Avlamè. These results are in agreement with those obtained by Massamba et al [27], Babaliyè et al [28], Niangoran et al [29], Elenga et al [30] and Ahouet et al [31].

3.2. Geotechnical characterization tests on mixtures

This part is dedicated to the results of the tests carried out on the different mixtures of lateritic gravel (GL) and granite crushed Dan (CG) formulated according to §2.3.2. The different mixtures are as follows: Mix 1 (90%GL+10%CG), Mix 2 (85%GL+15%CG), Mix 3 (80%GL+20%CG), Mix 4 (75%GL+25%CG), Mix 5 (70% GL+30%CG) and Mix 6 (65%GL+55%CG).

The results obtained on each mixture are as follows by trial:

3.2.1. Particle size analysis

The results from the particle size analysis of the different mixtures were used to draw the particle size curves (Figure 7).

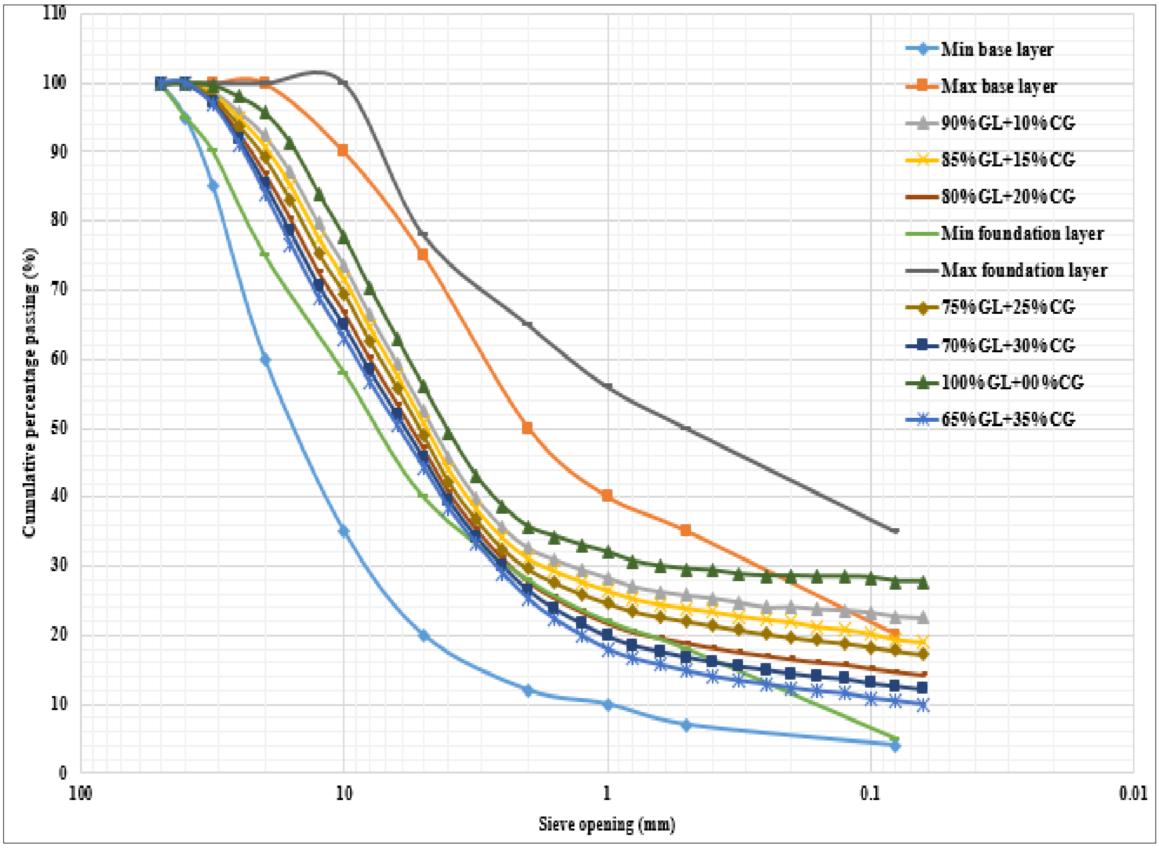

Figure 7 Sizing curves for mixtures

From the analysis of Figure 7, it appears that all the grading curves of the different mixtures are contained in the grading spindles of the materials intended for the base course of CEBTP [32], CEBTP [7], CEBTP [8] and AGEROUTE-Senegal [26].

Also, the evolution of the 80 µm sieve pass rate according to the different mixtures is projected on figure 8 below.

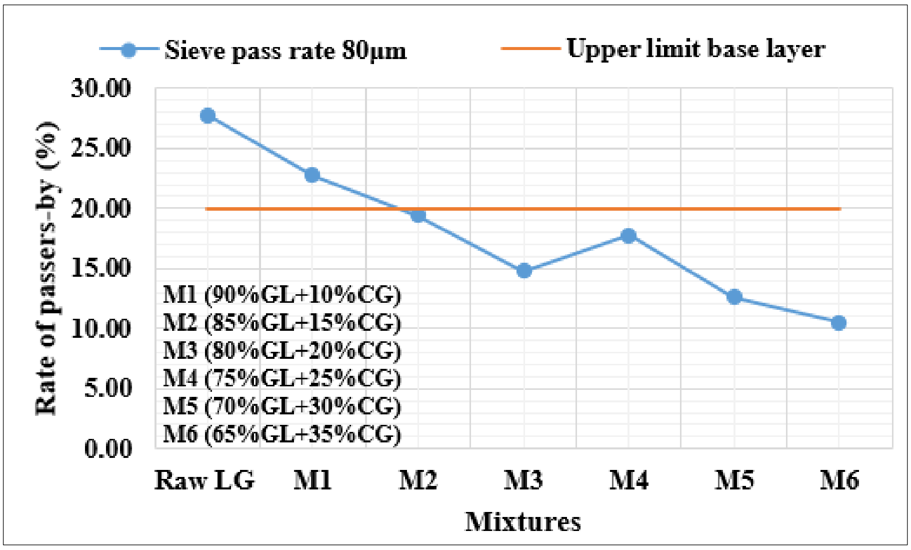

Figure 8 Evolving 80 µm sieve passings of mixtures

The analysis of this figure 8 allows to show that to lower the 80 µm sieve pass rate, below 20% in accordance with the CEBTP requirements for the base layer, it is necessary to substitute at least 10% of the raw material by granite crushed material. It appears from this analysis that the M1 mix does not meet this requirement for the 80 µm sieve pass rate to be used in base layer.

3.2.2. Limit of Atterberg

The results of the test of the Atterberg limit of the various mixtures made it possible to draw the curves translating the evolution of the liquid limit and the index of plasticity (Figure 9).

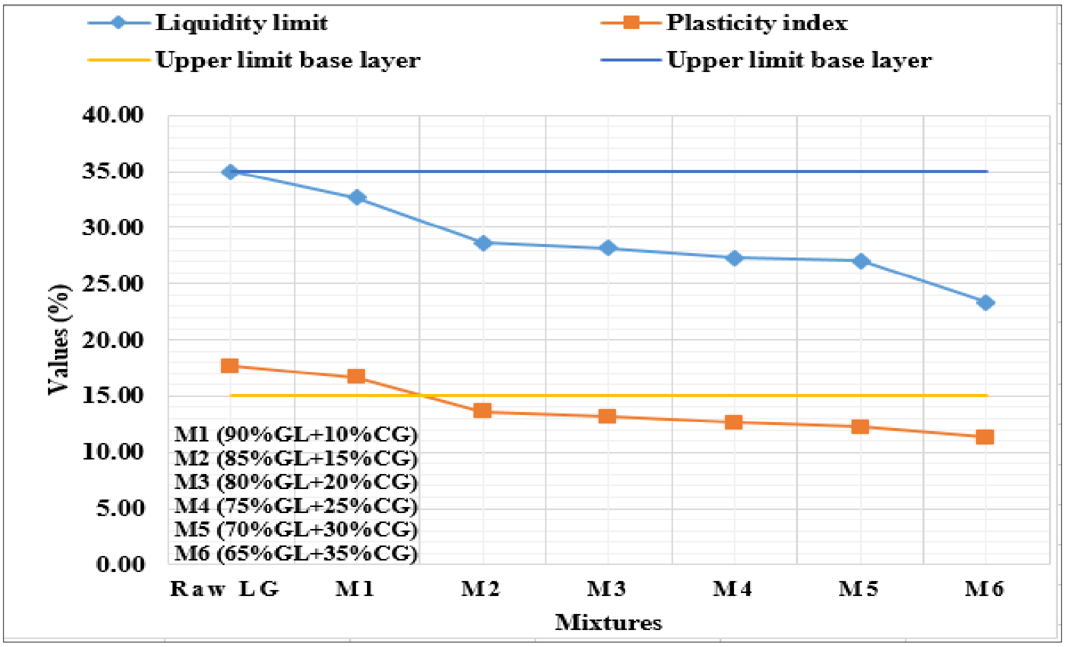

Figure 9 Evolution of the Atterberg limit as a function of the mixture

The analysis in Figure 9 above shows that:

- the liquidity limit WL decreases with the increase of the percentage of granitic crushed stone. For example, the liquidity limit of the raw lateritic gravel, i.e. 35.00%, decreases to 32.67% (case of M1), to 28.67% (case of M2), to 28.16% (case of M3), to 27.33% (case of M4), to 27.02% (case of M5) and to 23.33% (case of M6). According to the CEBTP criterion [7] concerning the liquidity limit, all the mixes can be used as a base course because they all have a liquidity limit of less than 35%.
- As for the plasticity index, it decreases progressively with the increase of the percentage of granite crushed. Indeed, the plasticity indexes of the mixes are respectively 16.67%, 13.67%, 13.16%, 12.67%, 12.26% and 11.33% for the targeted granite crushed mixes (Figure 9). All these values are lower than 20% for the use of lateritic gravel as a base course, according to the recommendations of the CEBTP guide [8].

All these results confirm the observations made in their work conducted by Massamba et al [27], Niangoran K. [29], Babaliyè [10], Babaliyè et al [28], Elenga et al [30], Jemal et al [33], Ahouet et al [31], Ndiaye [4] and Toe [34].

3.2.3. Modified Proctor test

The results of the modified Proctor test performed on the mixtures allowed the plotting of the curves of variations of the optimal moisture content and the optimal dry density (Figure 10).

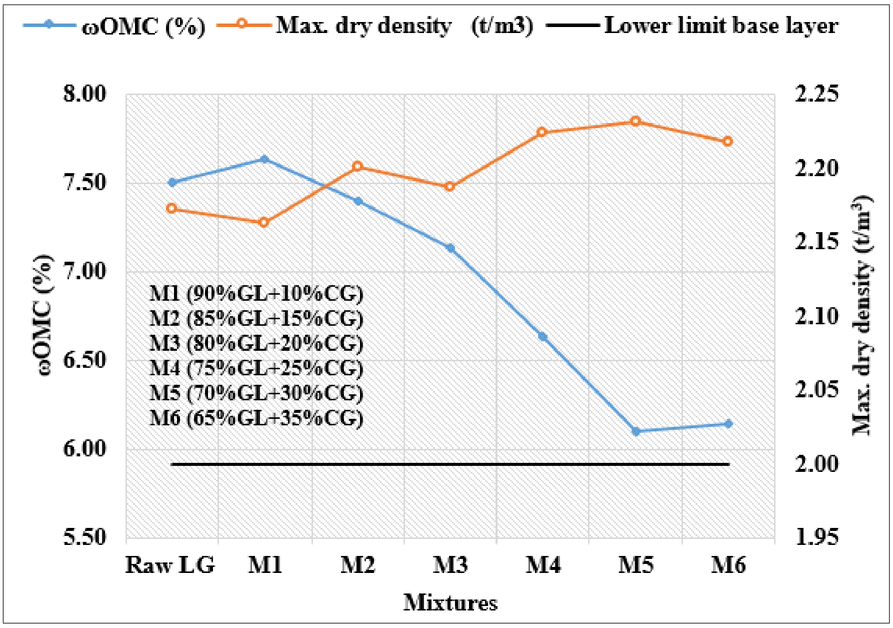

Figure 10 Evolution of optimal moisture content and optimal dry density

The analysis in Figure 10 above shows that:

The optimal water content drops as the percentage of granitic crushed material in the mixture increases. However, there is a recovery with the M1 mix (Figure 10.). These results show that the mixes are drier than the raw lateritic gravel [27].

The optimum dry density increases with increasing percentage of granitic crushed material in the mix. However, there is a drop when considering the M6 mix. Also, it can be seen that the dry density at OMC of each mix is higher than that of the raw lateritic gravel (Figure 10.). The increase in dry density may be due to the reinforcement of the grading skeleton of the lateritic gravel by the granitic crusher. It appears from the present analysis that all the dry density values determined at the optimum Proctor are higher than 2.00 t/m^3, as recommended by the CEBTP guides [7] revised in 2019 [8] and the AGEROUTE-Senegal catalog [26] for materials intended for the construction of base layer.

These results confirm the previous results obtained by Massamba et al [27], Babaliyè et al [28] and Elenga et al [30].

Figure 11 shows the variation between the dry density at OMC and the plasticity index as a function of the increase of the percentage of granitic crushed stone in the mix.

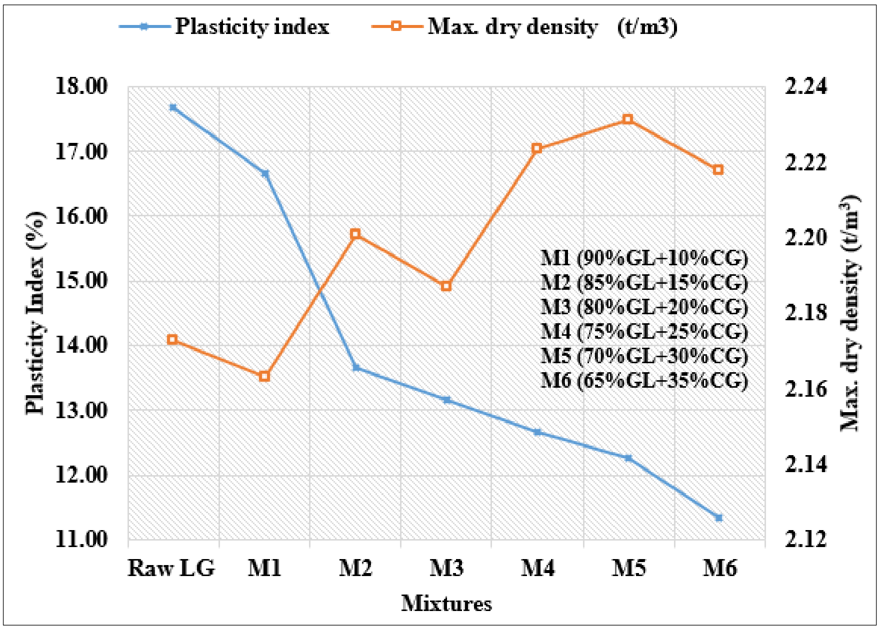

Figure 11 Evolution of the optimal dry density and plasticity index of mixtures

It can be seen from the analysis of Figure 11 that as the percentage of granitic crushed material increases, the plasticity index decreases while the dry density changes in a sawtooth pattern.

3.2.4. CBR test

The results of the 95% Optimum moisture content CBR test performed on the mixtures were used to plot the histograms in Figure 12 below.

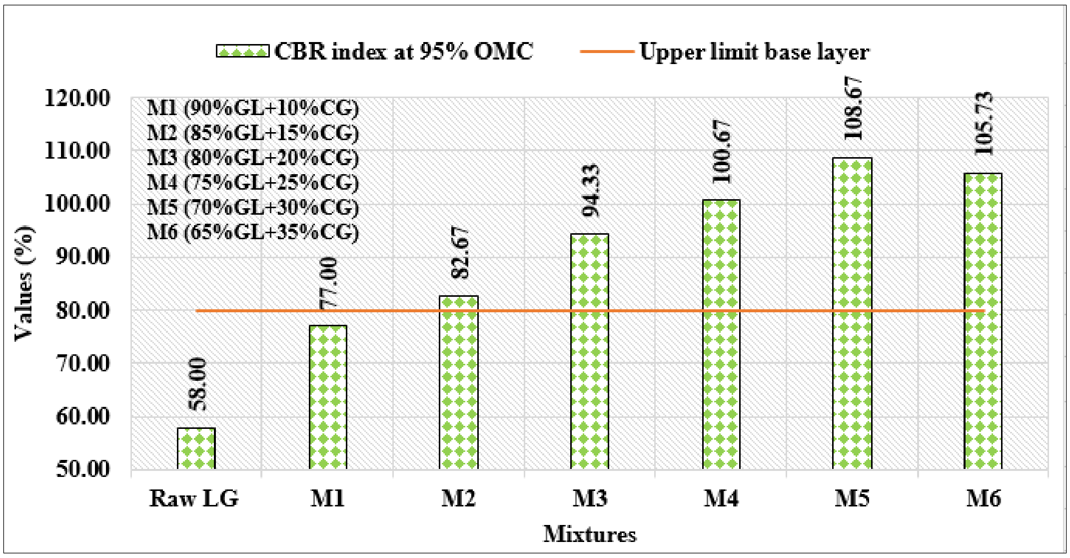

Figure 12 Variation of the CBR index at 95% OPM of the mixtures

From the analysis of figure 12, we note that the CBR index increases with the increase of the percentage of granitic crushed stone in the mixture. However, it should be noted that the CBR index drops for the M6 mixture. These results follow the same trend as the optimal dry density of the Modified Proctor test (see § of figure 10).

All the values of the CBR index at 95% of the OMC of the different mixes tested (M2, M3, M4, M5 and M6) are higher than 80%, the value required by the CEBTP [7] for granular materials to be used as a base layer for flexible pavements (Figure 12).

The present results also confirm those obtained by Ahouet et al [31] and Elenga et al [30], Massamba et al [27], Babaliyè et al [28] and Tankpinou et al [13].

Similarly, analysis of Figure 13 reveals that the relationship between dry density and CBR is non-linear (Figure 13.). This observation was made in previous work on the various possibilities of improving the characteristics of lateritic gravel by adding another granular material [4,27,35].

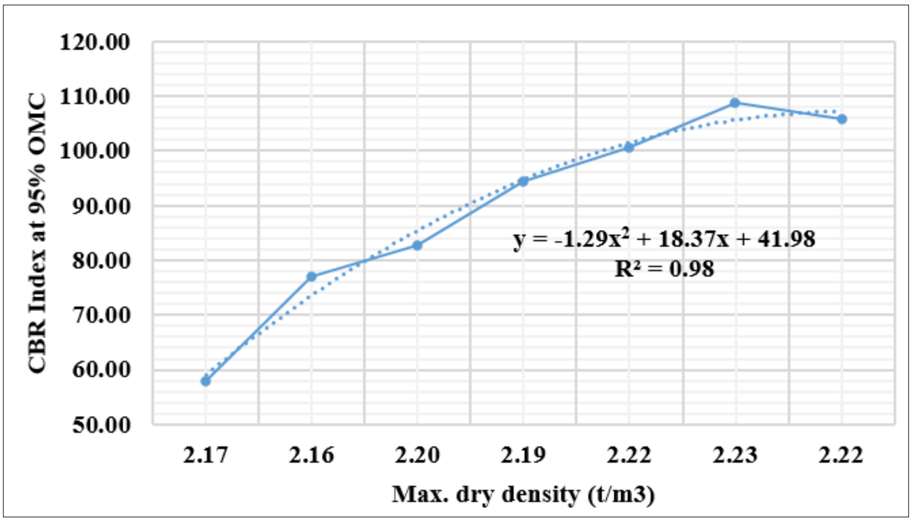

Figure 13 Relationship between CBR 95% OMC and optimal dry density

Table 3 presents a summary of the geotechnical characteristics of the materials developed from the lateritic gravel of Avlamè and the granitic crushed rock of Dan.

Table 3 Summary of the geotechnical characteristics of the lateritic gravel of Avlamè with the addition of granitic crusher

Designation		**% Passing the 80µm sieve**	**Liquidity limit (%)**	**Plasticity Index (%)**	**Methylene blue value**	**Organic Matter**	**Optimum moisture content (%)**	**Max. dry density (t/m3)**	**CBR Index at 95% OMC**	**Observation (Base layer)**
Raw LG		27.77	35.00	17.67	0.21	0.30	7.50	2.17	58.00	unsuitable
M1:90%GL+10%CG		22.77	32.67	16.67	0.34	0.23	7.63	2.16	77.00	unsuitable
M2 :85%GL+15%CG		20.27	28.67	13.67	0.31	0.23	7.40	2.22	82.67	suitable
M3 :80%GL+20%CG		14.76	28.16	13.16	0.30	0.26	7.13	2.19	84.67	suitable
M4 :75%GL+25%CG		17.77	27.33	12.67	0.34	0.29	6.63	2.22	94.33	suitable
M5 :70%GL+30%CG		12.64	27.02	12.26	0.29	0.31	6.10	2.23	100.67	suitable
M6 :65%GL+35%CG		10.51	23.33	11.33	0.24	0.31	5.77	2.26	108.67	suitable
CEBTP 1984 thresholds revised 2019	Foundation layer	< 35.00	< 50.00	< 25.00	-	-	-	≥ 1.80-2.00	≥ 30.00	-
	Base layer	< 20.00	< 35.00	< 20.00	-	-	-	≥ 2.00	≥ 80.00	-

From the analysis of this table, it appears that mixes M2, M3, M4, M5 and M6 meet the requirements of the CEBTP guide [7] and CEBTP [8] then the requirements of the AGEROUTE-Senegal catalog [26] for use as a base course for flexible pavements.

4. Conclusion

The present study was initiated to determine the mechanical characteristics of the lateritic gravel of Avlamè improved with granite crushed 0/31.5 of Dan for its use in road construction in Benin. In an empirical way, mixtures were made with different percentages of granitic crushed as follows: 10%, 15%, 20%, 25%, 30% and 35%. Thus, the results obtained from the characterization tests of road materials led to the following conclusions:

- Dan's 0/31.5 granitic crushed stone has good performance for use as a corrective (stabilizing) material.
- The 80 µm sieve pass rate decreases with increasing percentage of granitic crushed in the mix.
- The plasticity index of Avlamè lateritic gravel decreases with increasing percentage of granitic crushed material in the mix.
- The maximum dry density of the lateritic gravel of Avlamè increases with the percentage of granitic crushed stone in the mixture.
- The CBR index of the lateritic gravel of Avlamè increases with the percentage of granitic crushed stone in the mixture.

The mixes to know: Mix 2 (85%GL+15%CG), Mix 3 (80%GL+20%CG), Mix 4 (75%GL+25%CG), Mix 5 (70% GL+30%CG) and Mix 6 (65%GL+55%CG) can be used as a base course for flexible pavements in accordance with the normative requirements in force in Benin and South Sahelian Africa [7,8,26,36].

Therefore, it is important to determine the mechanical parameters, i.e., tensile strength, compressive strength and secant modulus of these mixtures targeted for the rational design of flexible pavements.

Compliance with ethical standards

Acknowledgments

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The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

Disclosure of conflict of interest

Authors have declared that no competing interests exist.

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