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Characterization of the Lateritic Soil of Kamboinsé (Burkina Faso)

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Abstract Laterite is a very common material in tropical countries. Good quality lateritic deposits are becoming increasingly rare. This material is used as a base course for most roads built in tropical Africa. These materials are selected on the basis of geotechnical test results in accordance with current standards. However, these materials do not perform well in situ after a short period of time, causing premature pavement degradation. This poor behavior can be ascribed to insufficient geotechnical testing to justify the choice of these materials in road construction. In this work, in addition to traditional geotechnical tests (particle size analysis, Atterberg limits, modified Proctor, CBR Index), compression tests were performed in addition to traditional geotechnical tests to determine compressive strength and elasticity modulus. Geotechnical tests carried out on the laterite of Kamboinsé according to the lithology of the quarry reveal that the characteristics decrease with depth and that the first layer can be used as a base layer. Cement improvement for small percentages (1, 2 and 3%) shows a clear improvement in mechanical characteristics. An addition of 2% cement allows the use of the second base layer, improvement of 3% allows the use of the first layer as a base layer. An addition of granite crushed granites of class 0/31.5 improved the physical properties of materials for additive percentages varying from 20, 25, 30 and 35% by weight of dry materials. This improvement allows the use of layers 1, 2 and 3 as a base layer for low traffic, layer 4 can be used as a base layer.

Keywords Laterites · Geotechnical characterization · Cement improvement · Litho-stabilization · Kamboinsé

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1 Introduction

In tropical Africa, the majority of road structures are in untimely degradation condition. This is due to several factors including material quality, poor drainage of pavement water and undersizing [5]. Our present study will involve geotechnical characterization of gravel and laterites from the quarry located in Kamboinsé by considering the different horizons that make up the quarry. The aim is on the one hand to be able to make recommendations on the ideal depth of exploitation of these materials, which layer would provide better characteristics (physical and mechanical). On the other hand, to know what dosage of cement and what percentage of crushed material would provide better mechanical characteristics.

2 Materials and Methods

2.1 Materials

Samples were taken according to lithological layers encountered. Thus, the kamboinse sample has four different layers that are rated KC1, KC2, KC3, KC4. For this quarry, the topsoil was stripped to a thickness of 0.27 m. Then comes the KC1 layer which is 1.9 m thick, the materials are red-brown in color. This is followed by the 2.7 m thick KC2 layer, which is brown in color with white nodules. These first two layers are located in the B horizon of this profile. The KC3 layer extends to a depth of 3.9 m and is made of purplish red and white spotted materials. Finally, the 8.3 m thick KC4 layer in red color. Samples are stored in hermetically sealed barrels to avoid variations in the natural water content of the materials.

The binder used to improve the mechanical characteristics of the materials is CimFaso CEMII/A-L 42.5R cement. Its dosage will be done according to 1–3% by weight for each layer.

2.2 Methods

Identification and mechanical tests were carried out on both raw samples and samples mixed with cement. This mixing was done by pre-wetting the raw material before adding the necessary quantities of cement to prevent loss of particles from the cement. Mechanical tests were performed on wet cylindrical samples with optimal water content and compacted with Modified Proctor energy. These samples are then stored in a room at room temperature. All tests were carried out according to the AFNOR standard (Association Française de Normalisation).

Table 1 Mechanical properties

Layer	CBR to 90% OPM	CBR to 95% OPM	CBR to 98% OPM	E (MPa)	Rc (MPa)
KC1	37	55	–	70.61	0.58
KC2	30	41	–	41.4	0.52
KC3	15	26	31	34.2	0.49
KC4	–	13	16	29.3	0.33

3 Results and Discussion

3.1 Raw Materials

Table 1 shows the results of the identification and compaction tests performed on the samples from this quarry. Blue values are low for all layers, showing that the materials have a low content of swelling clays. This result is confirmed by the results of the plasticity index because according to Casagrande chart, these thin parts are not very plastic silts. Therefore, the HRB classifications shows the same trend, KC2, KC3 and KC4 layers are classified as fine soils (respectively A5, A7-6, A7-5) while materials of KC1 layer, are sandy and gravelly soils with fine (A2-5). Plasticity indices of all layers of the quarry are less than 15% which is the limit for base layer use according to CEBTP [2]. Proctor test shows that for Kamboinsé quarry, optimal dry densities decrease with depth. From the point of view of optimal dry density, KC1 layer of kamboinse laterite can be used both as a base layer and as a foundation layer because the latter is superior to 2 t/m^3 [2]. KC2 layer can be used as a base layer because its density is higher than 1.8 t/m^3.

First, it can be seen that CBR index decreases with depth for Kamboinsé quarry. The lower the fine content, the lower the plasticity index, the lower the optimal water content, the higher the CBR index. Mechanical properties of this soils are poor except thus of KC1 layer which shows 55% of CBR index, 70.61 MPa of modulus and a compressive stress of 0.58 MPa. This results show that only KC1 layer can be used as sub-base layer in road [2].

To improve the mechanical characteristics of lateritic soil, this material is mixed with cement. In this part, lateritic soil will be mixed with low doses of cement so that they can be used in flexible pavements.

3.2 Improved Cement Laterite

Geotechnical and Mechanical Properties

Table 2 shows that plasticity index decreases, water content decreases slightly and the dry density increases with the cement content. This decrease is desirable from a stabilization perspective. Similar results were obtained by other authors with Portland

Table 2 Physical and compaction properties

Identification of samples	Atterberg limits			Modified Proctor		ICBR to 95% OPM	ICBR to 98% OPM
	ωL	ωP	Ip	ωopm (%)	γd (t/m^3)		
0% KC1	47.1	38.2	8.9	13.5	2.16	55	–
1% KC1	46.4	37.7	8.8	8	2.25	70	85
2% KC1	45.4	37.4	7.9	9.6	2.27	142	146
3% KC1	43.8	36.7	7.13	10.4	2.35	175	190
0% KC2	46.7	37	9.7	16.2	1.81	41	–
1% KC2	46.1	37.2	9	16.1	1.85	59	61
2% KC2	45.5	37	8.5	15.1	1.93	76	92
3% KC2	44.7	37	7.8	14.2	1.97	108	117
0% KC3	44.8	34	10.9	19.4	1.76	20	25
1% KC3				20.2	1.76	30	31
2% KC3				20.4	1.74	46	48
3% KC3				20.4	1.75	80	84
0% KC4	42.4	29.4	13	20	1.64	13	16
1% KC4				21.6	1.71	26	31
2% KC4				20.5	1.74	31	34
3% KC4				25.4	1.63	71	102

cement [4] and it has been postulated that when cement is mixed with cohesive fine-grained soils, there is cation exchange, flocculation and soil agglomeration, which decreases the soil plasticity index and should reduce the optimal water content due to decrease in its specific surface. This means that cement reduces the clay activity of the material.

Based on the specifications of CEBTP [2], only KC1 layer-improved cement can be used as base layer since its density is greater than 2 t/m^3.

It is noted that CBR index increases with cement content, which shows that addition of cement increases the mechanical characteristics of laterites. This increase is due to the stiffening of laterite through hydration of cement which develop hydrates as hydrated calcium silicate (CSH). The CBR of KC2 improved to 3%, as well as those of KC1 layer that improved to 2 and 3% are greater than 100, therefore they can be used as a sub-base layer according to CEBTP [2]. However, only KC1 layer improved with 3% cement can be used as a base layer because it is higher than 160.

Table 3 shows the evolution of Young's modulus (according to the standard NF EN 13286-43) and the compressive strength (according to the standard NF EN 13286-41) of kamboinse laterites in relation to the percentage of cement after 7 days of curing. In all cases, the modulus increases with the cement content. Only KC1 layer improved to 3% has a modulus superior to 300 MPa. This value guarantees the good mechanical performance of a lateritic gravelly material and its use as a base layer of road structure [1].

Table 3 Variation of Young's modulus and compressive strength according to layers and cement contents

Parameters	% Cement	KC1	KC2	KC3	KC4
E (MPa)	0% Cem	90.34	62.52	52.25	56.8
	1% Cem	64.5	373.5	57.6	121.65
	2% Cem	234.86	467.6	69.04	215
	3% Cem	603.75	307.2	95.12	229
Rc (MPa)	0% Cem	0.36	0.43	0.25	0.34
	1% Cem	0.57	0.56	0.71	0.42
	2% Cem	1.57	1.75	1	0.95
	3% Cem	2.42	2.34	1.07	0.6

E: Young's Modulus
Rc: Compressive strength
Cem: Cement

The compressive strength increases with increasing cement content. The same trend was noted by Millogo et al. [5]. Only KC1 and KC2 layers (2.42 and 2.34 MPa respectively) improved to 3% Cement can be used as a base layer because they are between 1.8 and 3 MPa.

3.3 *Litho-Stabilized Laterite*

Geotechnical and Mechanical Properties

Apart from cement stabilization, laterites used in road construction can be improved by substituting part of their weight with sand, crushed shells, palm nut shells, vegetable fibers [3]. This last part is devoted to improving laterite by adding crushed material. To this end, improvement will be achieved by adding granites of class 0/31.5. Different percentages of crushed granites ranging from 20, 25, 30 and 35% by dry weight were added to the raw laterite.

Table 4 presents the evolution of the optimal density with the percentage of granite crushed added. This is due to the use of coarse granular materials in the mixture,

Table 4 Variation in density according to the percentage of crushed material added

% Granites	KC1	KC2	KC3	KC4
0% G	2.16	1.81	1.76	1.64
20% G	2.17	1.96	1.86	1.77
25% G	2.23	1.89	1.95	1.81
30% G	2.15	2.05	1.92	1.81
35% G	2.04	2.32	2	1.85

allowing a better interweaving of grains and consequently, the formation of a denser soil layer. For 35% of granites, there is a sudden decrease in density. This KC1 material had the best densities, this decrease can be explained by the excessive presence of coarse grains which eventually increase the voids index of the mixture. The best densities are obtained for a contribution of 35% for the other materials, thus bringing the densities of KC2 and KC3 into the density range of a base layer (greater than 2 t/m^3).

The optimum water content of layers KC1, KC2, KC3 and KC4 varies respectively from 13.5 to 8.03; from 16.2 to 8; from 19.4 to 12.3; from 20 to 13.6 according to the percentage of granite added. It is clear that this water content decreases with the percentage of granites, the lowest values are obtained at 35% granites.

Table 5 shows the variation in CBR index according to the percentage of granite. CBR increases with the percentage of granite. This is due to the fact that the mixture becomes increasingly insensitive to water as shown by the considerable decrease in water content and increase in density [3]. The maximum values for KC1 and KC2 are given by 30% granite, and for soil layers KC3 and KC4 by 35% crushed. From a 30% improvement, all layers can be used as sub-base layer, for the same percentage, KC1 and KC2 can be used as base layer. A 35% KC3 can be used as a base layer.

As for compressive strength, there is an increasing trend, but results are dispersed dû to the homogenous of samples. After improvement from 30%, all layers can be used as sub-base layer except KC4 because this resistance is between 0.5 and 1.5 MPa. Modules are presented in Table 5. These values are quite dispersed certainly due to the difficulty in fixing sensor supports due to the crumbling of laterite. But overall,

Table 5 Variation in the mechanical properties of the different layers according to the percentage of crushed material added

Parameters	% Granite	KC1	KC2	KC3	KC4
E (MPa)	0% G	90.34	62.52	56.8	52.25
	20% G	168.35	38.83	10.63	8.53
	25% G	190.034	18.18	21.57	12.36
	30% G	206.71	43.8	42.36	17.76
	35% G	112.586	204.54	41.96	26.52
Rc (MPa)	0% G	0.36	0.43	0.25	0.34
	20% G	1.72	0.76	0.32	0.31
	25% G	0.51	0.51	0.32	0.35
	30% G	0.57	1.114	0.57	0.32
	35% G	0.91	0.73	0.55	0.26
CBR to 95% OPM	0% G	55	41	20	13
	20% G	76	74	24	16
	25% G	79	84	34	18
	30% G	86	101	44	56
	35% G	74	70	84	58

we notice a clear increase in the module depending on the rate of crushed material, more pronounced on the KC1 layer. The values obtained for KC1 from 20% and KC2 to 35% are in the module range of lateritic materials used in pavement layers. They are higher than that obtained by Millogo et al. [5] for the raw laterite of Sapouy, which was around 100 MPa.

4 Conclusion

From these studies, we observe that in their raw state, these materials can only be used as foundation layers. Surface materials such as KC1 layer are recommended. Cement improvement and litho-stabilization show that mechanical and physical properties of these materials can be improved and allow their use as base layer for light traffic. For cement a percentage of 2% is sufficient, for crushed cement a percentage of 30% is sufficient.

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