

Contribution to the Optimization of Earthwork and Pavement Construction: Geotechnical Study of Quarries in the Thiès Region and Surrounding Areas

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ABSTRACT

This study aims to characterize and optimize the use of lateritic materials extracted from quarries in the Thiès region and surrounding areas for earthworks and pavement construction. Seven lateritic gravel materials from Keur Samba Kane, Ngoundiane, Sindia, Yéba, Tchicky, Kiniabour, and Lam-Lam were investigated through particle-size distribution, Atterberg limits, methylene blue value (VBS), modified Proctor, apparent density, swelling/expansion coefficient, and California Bearing Ratio (CBR) tests. The materials were subsequently assessed according to CEBTP, AGEROUTE Senegal, and GTR 2000 and 2023 requirements. The results reveal significant variability in the geotechnical properties of the studied laterites. The optimum moisture content ranges from 7.25% to 14.80%, while the maximum dry density varies from 1.869 to 2.230 g/cm³. Keur Samba Kane exhibits the highest maximum dry density (2.230 g/cm³) and the highest soaked CBR at 95% compaction, reaching 87%. Lam-Lam also presents a high bearing capacity, with a CBR

of 72%. In contrast, Ngoundiane and Tchicky show lower bearing capacities, with CBR values of 39% at 95% compaction. The VBS values range from 1.2 to 2.6, indicating variable clay activity and sensitivity to water. Keur Samba Kane and Lam-Lam present the lowest plasticity indices, 13.7% and 14.15%, respectively, whereas Ngoundiane reaches the highest value of 29.9%. According to the GTR 2023 classification, Keur Samba Kane and Lam-Lam are classified as G3 materials, whereas the materials from Sindia, Ngoundiane, Tchicky, Yéba, and Kiniabour are classified as I2. The results indicate that Keur Samba Kane and Lam-Lam are the most suitable materials for pavement foundation and base layers because of their favorable grading, relatively low plasticity, high dry density, and high bearing capacity. The other materials are generally suitable for subbase or lower pavement layers, although Ngoundiane and Tchicky require improvement or treatment before being considered for heavily loaded base courses. The expansion coefficients, ranging from 1.17 to 1.37, also provide useful information for estimating quarry-to-site material

requirements and optimizing earthwork logistics. These findings confirm the strong heterogeneity of lateritic resources within the Thiès region and demonstrate the importance of combining particle-size distribution, plasticity, clay activity, compaction characteristics, and bearing capacity when selecting materials for road construction. The study contributes to the rational management of lateritic resources and provides practical criteria for selecting quarry materials according to their intended pavement layer. It also provides a basis for future quarry mapping and spatial optimization of lateritic material resources in the Thiès region.

Keywords: Lateritic gravel; Geotechnical characterization; Thiès region; Quarry materials; Pavement Construction; Earthworks; GTR 2023; AGEROUTE; CEBTP; Senegal.

1. INTRODUCTION

The quality and durability of road infrastructure depend largely on the materials used in earthworks and pavement structures. In Thiès and its surroundings, a region known for its abundance of quarries, the geotechnical characterization of materials is of particular importance. Indeed, the increase in demand for construction materials leads to increased exploitation, sometimes at the expense of the performance and durability of the structures.

This study is conducted within this context and aims to thoroughly analyze the physical

and mechanical properties of materials extracted from the quarries of Thiès. The objective is to better understand their behavior and suitability for use in road and earthwork projects, in order to contribute to the construction of more reliable and durable infrastructure.

The analysis is based on a series of standardized tests that allow the materials to be classified according to CEBTP, AGEROUTE, and GTR 2023 standards, and to propose recommendations for their use based on their geotechnical behavior.

2. Presentation of the study sites

Laterite, formed by the chemical weathering of rocks in hot and humid climates, is a widely used resource in tropical regions. Mined in open pits, it possesses favorable geotechnical properties that make it a material of choice in road construction, particularly for subgrade, base, or subbase layers, thanks to its good bearing capacity and compressive strength. Meanwhile, sands—loose materials resulting from the erosion or decomposition of massive rocks such as granite—are very abundant and cover more than 70% of the national territory. Their formation dates back mainly to the Upper Pleistocene, during periods of sea retreat.

This study was conducted at several laterite and sand quarries located in the Thiès, Diourbel, and Dakar regions. Their locations are shown in Figure 1.

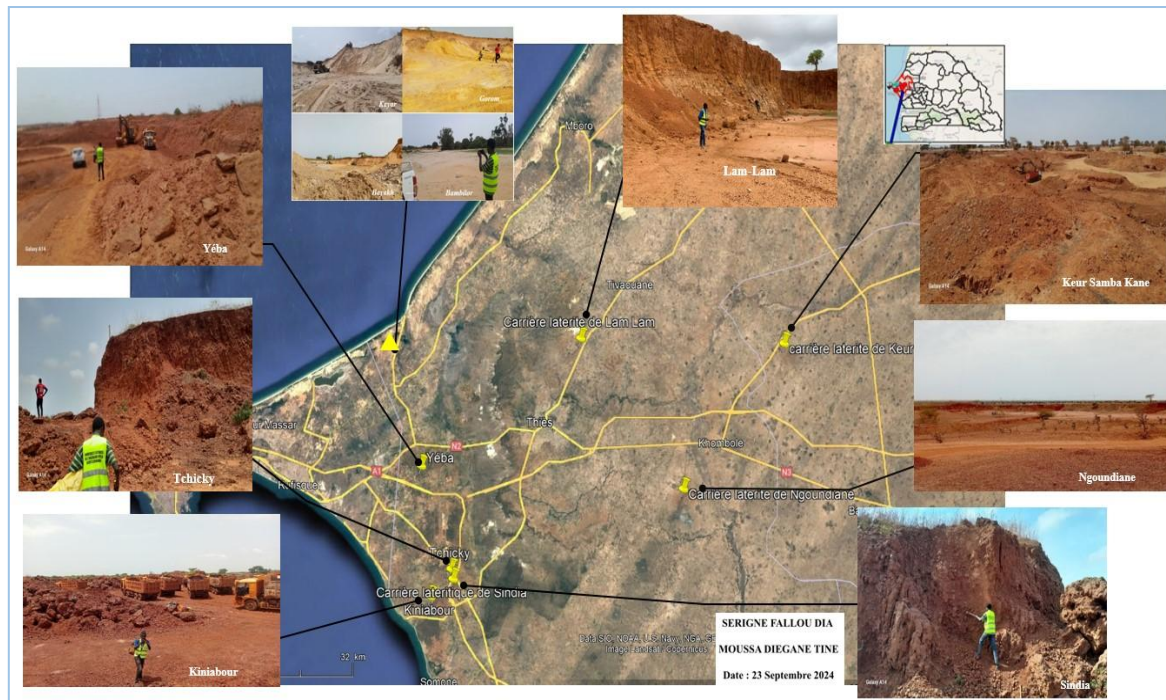


Figure 1 : Map of Quarry Locations

Laterite quarries:

- Keur Samba Kane: located in the Bambey department (Diourbel region), at coordinates 14.8966216°N and - 16.5981861°E.
- Ngoundiane: Thiès department, at coordinates 14.7114798°N and - 16.7426600°E.
- Sindia: Mbour Department (Thiès), at coordinates 14.6103899°N and - 17.0512310°E.
- Tchicky: Mbour (Thiès) department, at coordinates 14.6331460°N and - 17.0659750°E.
- Yéba: Thiès Department, at coordinates 14.7317566°N and -17.1093290°E.
- Kiniabour: Mbour Department (Thiès), at coordinates 14.5765386°N and - 17.0831160°E.
- Lam-Lam: Tivaoune Department, at coordinates 14.8952094°N and - 16.8749620°E.

Particle size analysis: The objective is to determine the distribution of particles in a material, larger than $63\mu m$, according to their size using a series of square-mesh sieves with decreasing mesh sizes. Regarding lateritic gravels, which are loose soils with a grain size of 0.20 to 0.40 mm, containing 10

to 35% of fines passing through a $63\mu m$ sieve and 20 to 60% of coarse particles retained by a 2- sieve, forming a “skeleton [1]. The CBR test evaluates the bearing capacity of a soil compacted to optimal moisture content. After saturating the sample, a piston penetrates at a constant speed, and the measured forces are compared to those of a reference material [5]. Atterberg limit test: The Atterberg limits apply only to the fine particles in a soil (size $< 400\mu m$). By varying the moisture content, the soil can be solid, plastic, or liquid. These thresholds are called the plasticity limit and the liquidity limit [2]. Methylene Blue Value (VBS) (Standard P 94-068): The methylene blue value (VBS) measures the clay content of a soil[6]. The test involves mixing the sieved sample with water and methylene blue, then observing the appearance of a ring on filter paper indicating the end of the test [4]. Compaction characteristics, including the optimum moisture content and maximum dry density, were determined using the Standard Proctor and Modified Proctor tests according to NF P 94-093 (1999) [3]. The cleanliness of the granular material was assessed by determining the sand equivalent value of the

0/2 mm fraction in accordance with NF EN 933-8+A1 (2015) [6].



Figure 2 : Various tests conducted in the geotechnical laboratory to identify lateritic materials from quarries

The classification of our various materials is based on recognized technical specifications. According to the Experimental Center for Building and Public Works (CEBTP), the basic criteria for classifying road materials primarily refer to the recommendations established in the Guide to Pavement Design

for Tropical Countries (CEBTP, 1972 and 1980 editions, revised in 1984), see Table 1. In addition, the specifications in the Senegal Catalog (AGEROUTE, Design Catalog for New Pavements in Senegal, November 2015) also serve as an essential reference for the evaluation and selection of materials, see Table 2.

Table 1 : CEBTP 1972 and 1984 specifications for use [8], [7]

Table 1: CEBTP 1972 and 1984 specifications for use [6], [7]

CEBTP 1972					CEBTP 1984				
Sieve	C Foundation		C Base		Sieve	C Foundation		C Base	
	Loop		Loop			Loop		Loop	
	Min	Max	Min	Max		Min	Max	Min	Max
38	80	100	85	100	50			100	100
19	65	100	70	100	40	95	100	95	100
10	50	100	50	95	31.5	90	100	85	100
5	35	100	40	90	20	75	100	60	100
2.5	25	80	30	80	10	58	100	35	90
0.7	15	55	15	45	5	40	78	20	75
0.8	5	35	5	20	2	28	65	12	50
	$\rho_{dOPM} \geq 1,9 g/cm^3$		$\rho_{dOPM} \geq 2 g/cm^3$		1	22	56	10	40
	WL≤ 50		WL≤ 35		0.5	18	50	7	35
	IP≤ 25		IP≤ 15		0.08	5	35	4	20
	Swelling≤ 1%		Swelling≤ 0,3%					$\rho_{dOPM} \geq 2 g/cm^3$	
								IP≤ 15	
								Swelling< 1%	

Table 2 : Specifications from the Design Manual for New Pavements in Senegal, November 2015 [9].

Sieve		40	31.5	20	10	5	2	1	0.5	80
Specification	Min	100	85–100	65–99	40–85	25–70	16–50	9–40	5–35	4–20 (B) 4–30 (F)
	Max	100	84–97	72–88	55–70	30–48	18–35	15–32	13–28	10–17

RESULTS AND DISCUSSION

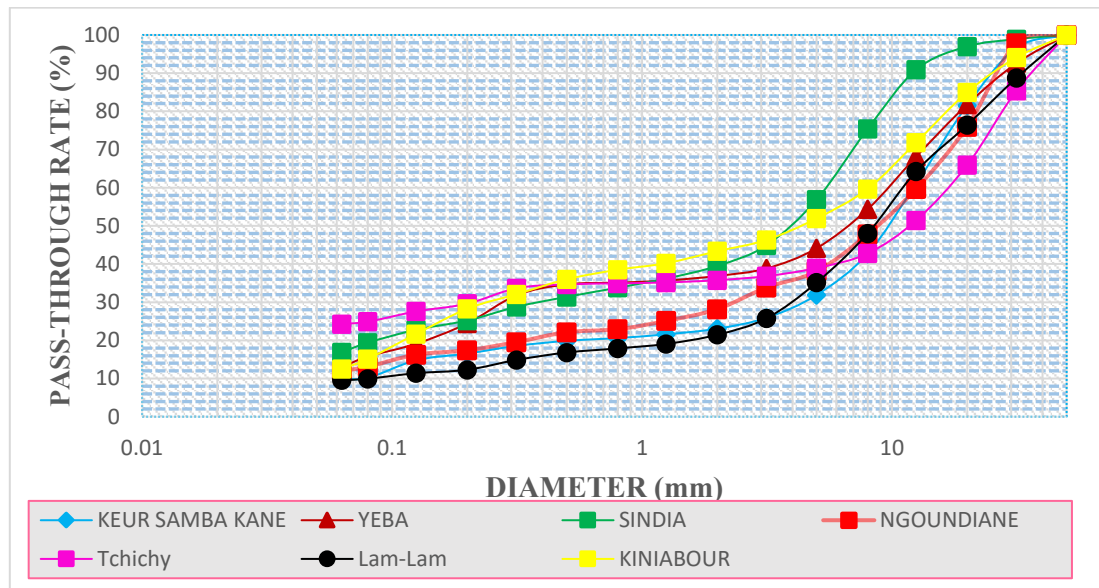


Figure 3 : Particle size distribution curve of the various lateritic gravel samples

Table3 : Uniformity coefficient results for the studied samples.

Quarries	Keur S Kane	Ngoundiane	Sindia	Yéba	Tchicky	Kiniabour	Lam-lam
Samples	KSK3	NG3	SD 3	YB	TC	KB	LL
D60 (mm)	12.5	13	6	10	14	8.5	12
D30 (mm)	4.7	4	0.4	0.29	0.22	0.22	4.3
D10 (mm)	0.087	-	-	-	-	-	0.09
Cu	143	-	-	-	-	-	133

percentage of fines greater than 10% on the 63 μm sieve, except for the Keur Samba Kane and Lam-Lam laterites, which have the lowest values. Some lateritic materials have very high percentages of fines, which prevents the determination of D10 and Cu. A

sedimentometric analysis would be necessary to complete the curve and calculate D10. According to the GTR 2023 classification, these studied soils would still have a $D_{60} > 400 \mu\text{m}$, which gives them uniformity coefficients well above 6, see Table 3.

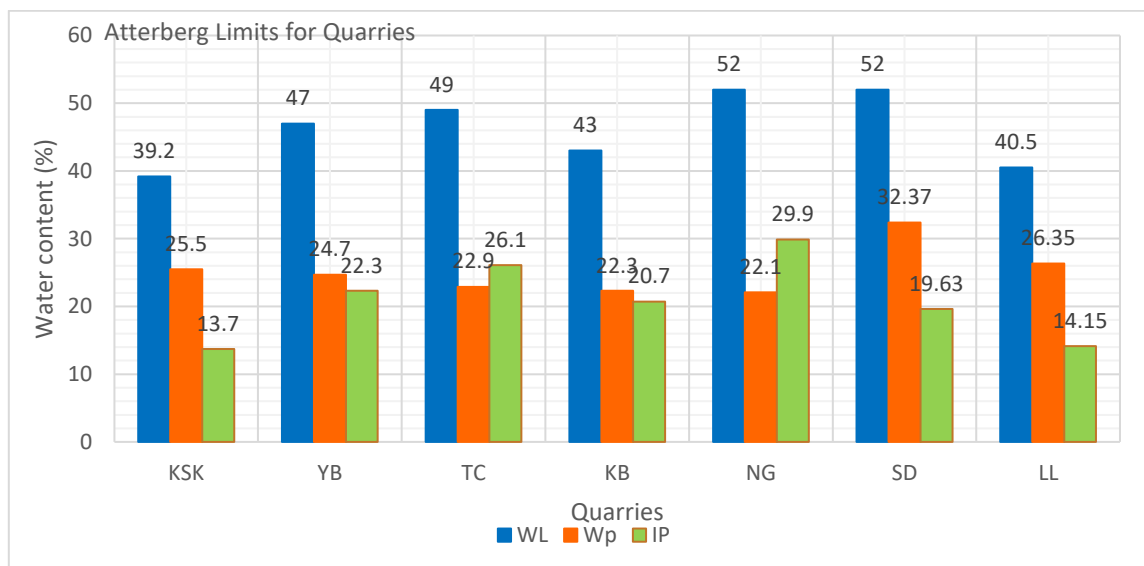


Figure 4 : Atterberg limit results

The laterites were classified according to standard NF P 94-051 and the specifications of GTR 2023. Keur Samba Kane and Lam-Lam have the lowest plasticity indices, while Sindia and Ngoundiane have the highest. All are suitable for a subbase layer, but none are

approved for a base layer according to CEBTP 72, see Figure 4.

The results of the methylene blue tests conducted on the lateritic materials are shown in Figure 5.

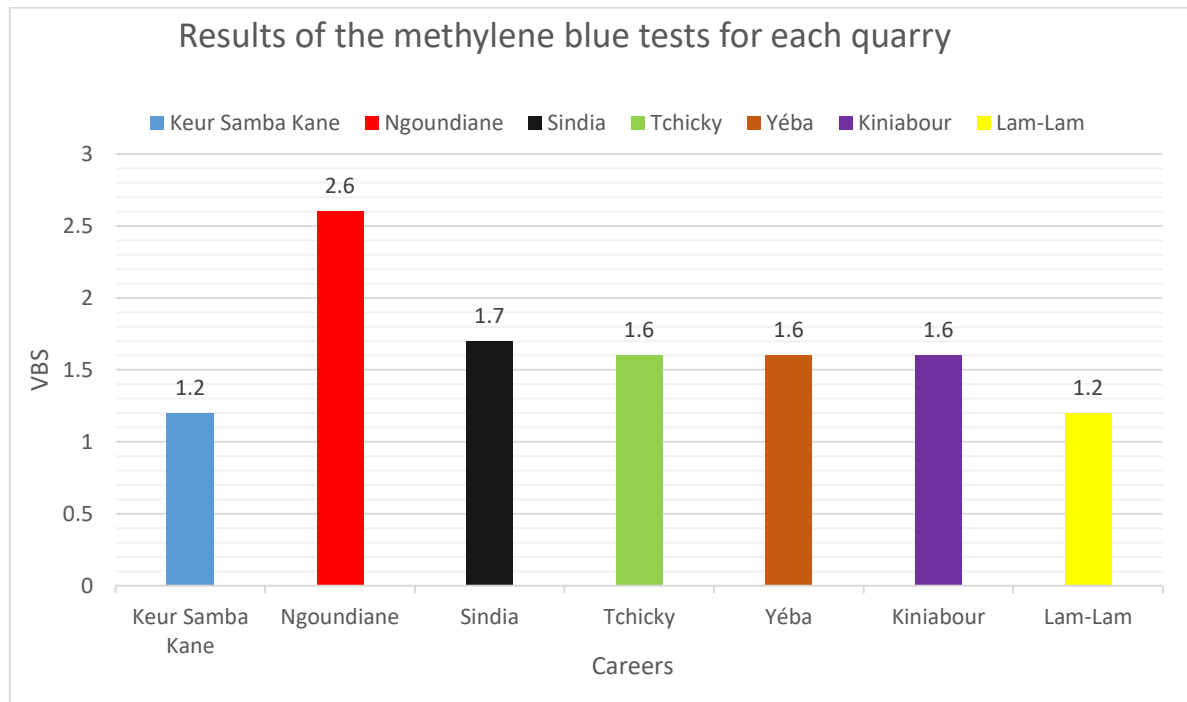


Figure 5 : Methylene Blue test results for each quarry

The lowest methylene blue absorption value was observed in the samples from Keur Samba Kane and Lam-lam, while those from Ngoundiane had the highest value. These materials, containing a low percentage of clay (1.2%), are less clayey and correspond to water-sensitive soils.

In contrast, the samples from Sindia, Kiniabour, Tchicky, and Yéba, with values ranging from 1.5 to 2.5, are sandy-loamy soils. For Ngoundiane, we have loams with low to moderate plasticity.

Table 4 : Results of modified Proctor tests on lateritic gravel samples

Quarries	Keur S Kane	Ngoundiane	Sindia	Yéba	Tchicky	Kiniabour	Lam-Lam
Echantillon	KSK1	NG3	SD2	YB	TC	KB	LL
W_{OPM} (%)	7.25	14.8	10.7	12.05	12.4	8.08	10.1
ρ_d (g/cm ³)	2.23	1.869	2.075	2.039	1.916	2.025	2.09

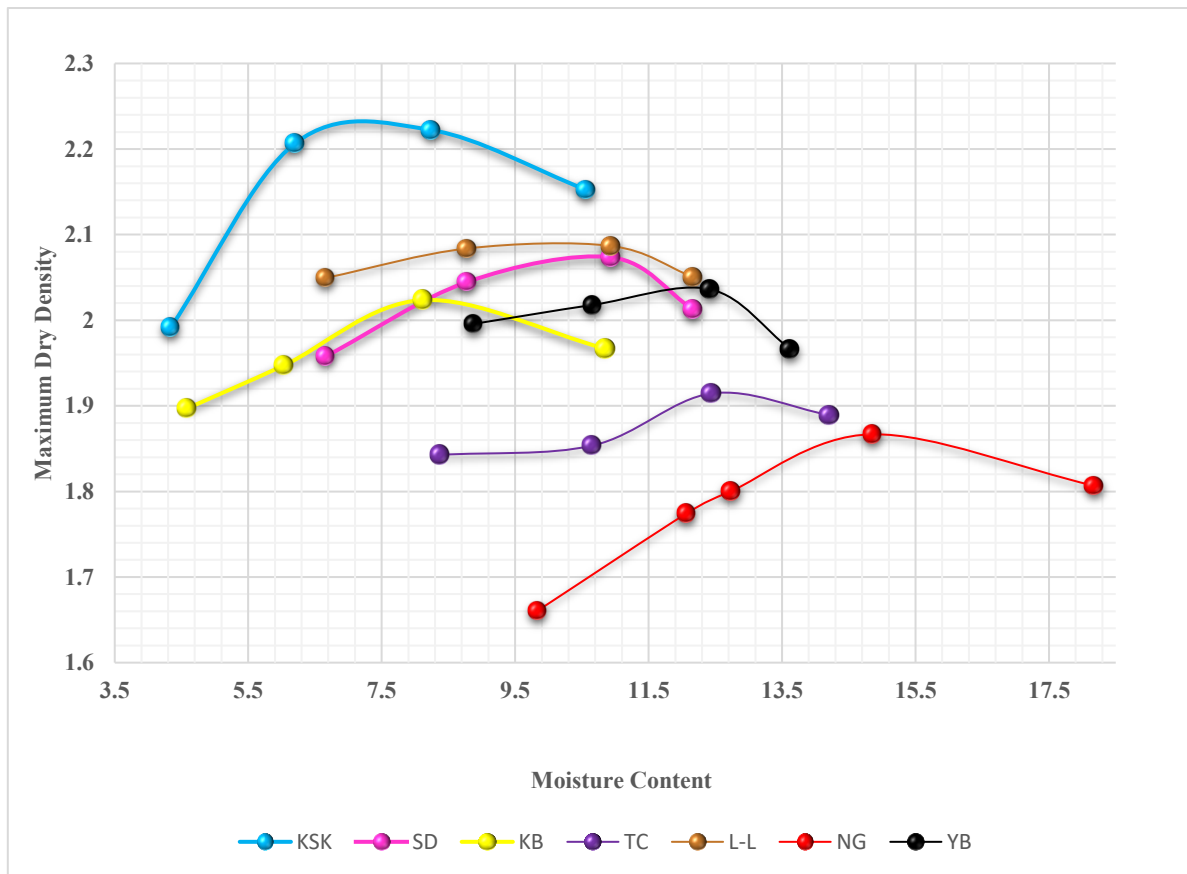


Figure 6 : Modified Proctor test of various lateritic gravels

Water contents range from 7.25% to 14.8%, with the lowest values at Keur Samba Kane and the highest at Ngoundiane. Maximum dry densities range from 1.869 to 2.23 g/cm³, with the highest observed at Keur Samba Kane. Ngoundiane and Tchicky require a higher optimal moisture content but achieve lower densities than the other sites. With the exception of Ngoundiane, all materials meet the CEBTP specifications for foundation layers, but only Tchicky is non-compliant for a base layer, see Figure 6 and Table 4.

To determine the bulk density, simply fill a mold of known volume with material, then weigh the material. The weight of the material collected over the given volume allows the bulk density

To evaluate the material's expansion during compaction on-site, it is first necessary to calculate the total density from the dry density at 95% compaction, taking into account the moisture content. The expansion can then be calculated by dividing the total density by the bulk density, according to the following Equation 1.

$$\text{Expansion coefficients} = \frac{\gamma_{\text{Total (95\%)}}}{\gamma_a} \quad \text{Eq 1}$$

$$\text{Where: } \gamma_{\text{sec opt (95\%)}} = 0,95. \gamma_{\text{sec opt (100\%)}} \quad \text{Eq 2}$$

$$\gamma_{\text{Total (95\%)}} = \gamma_{\text{sec opt (95\%)}} (1 + \omega_{\text{opt}}) \quad \text{Eq 3}$$

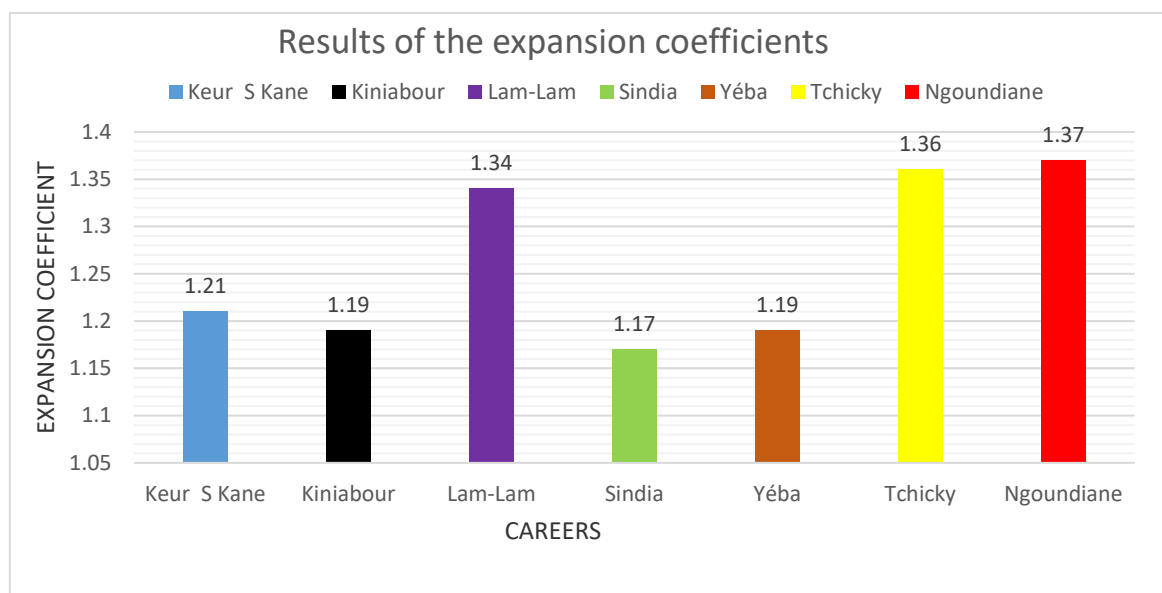


Figure 7 : Results of the expansion coefficients

Based on the results recorded in the table, we observe that Keur Samba has the highest bulk density of 18.76 kN/m³ with a expansion coefficient of 1.21 at 95% compaction, indicating that a volume of 1.21 m³ of material taken from this quarry will be

compacted into 1 m³ at the construction site, see Figure 7.

The calculated expansion coefficients will allow us to estimate the volumes of material to be transported from the quarry to the construction sites by machinery.

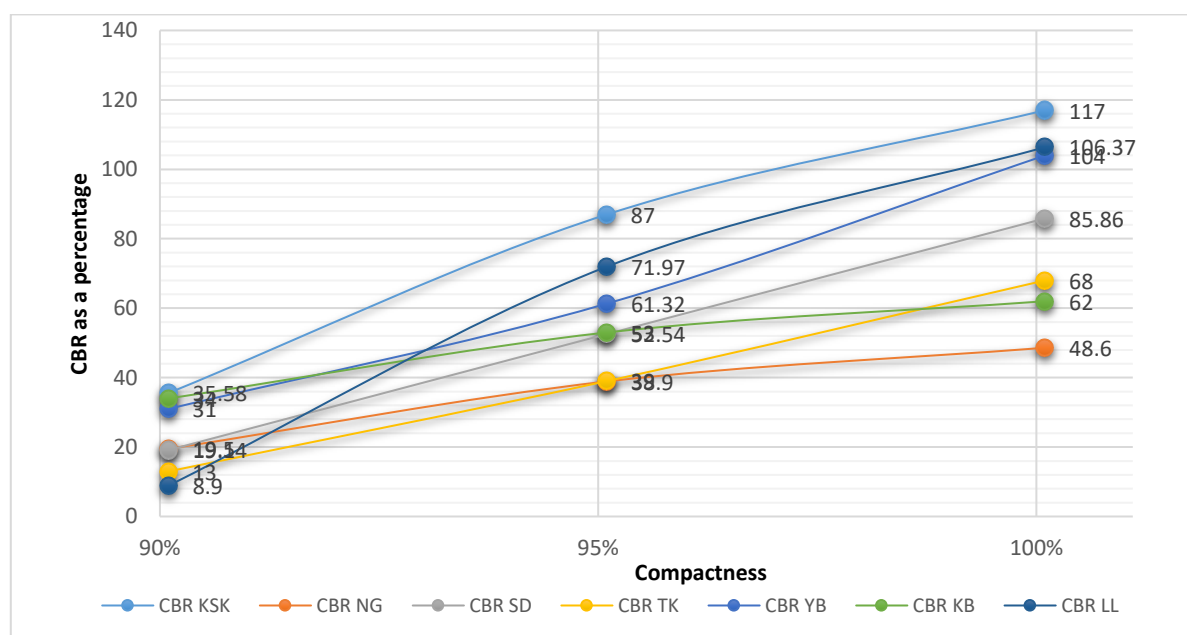


Figure 8 : CBR values of various lateritic gravels

Keur Samba Kane exhibits the highest compaction (87 to 95%), followed by Lam-lam, Yéba, Kiniabour, and Sindia, while Ngoundiane and Tchicky have the lowest values. The CBR values at 95% compaction confirm that all materials comply with the requirements for subbase layers according to

CEBTP 72, 84, and AGEROUTE. For base layers, only the lateritic gravels from Keur Samba Kane, Yéba, and Lam-lam are acceptable. Keur Samba Kane, with a CBR of 87%, fully meets the requirements for use in a base course; see Figure 8.

Table 5 : Classification of lateritic gravel from various borrow pits

Laterite Quarries		Keur S. Kane	Sindia	Ngoundiane	Tchicky	Yéba	Kiniabour	Lam-lam
Dmax	mm	< 50						
2 mm	%	21.86	39.5	37.60	35.76	36.88	43.35	21.46
0.08 mm	%	9.94	19.4	24.19	24.9	19.13	17.81	9.96
0.063 mm	%	9.80	16.9	19.86	23.2	15.77	16	9.57
D10	mm	0.087	-	-	-	-	-	0.09
D60	mm	12.5	6	7.9	14	10	8.5	12
Cu	-	143 > 6	D60> 400μm					133> 6
			> 6					
WL	%	39.2	52	52	49	47	43	40.5
Wp	%	25.5	32.37	22.1	22.9	24.7	25.9	26.35
Ip	%	13.7	19.63	29.9	26.1	22.3	17.1	14.15
VBS	%	1.2	1.7	2.6	1.6	1.6	1.6	1.2
Apparent density	kN/m³	18.76	18.52	14.85	14.97	18.10	17.46	16.29
Expansion Coefficient		1.21	1.17	1.37	1.36	18.10	1.19	1.34
Wopt	%	7.25	10.7	14.8	12.4	12	8.08	10.3
γd	g/cm³	2.23	2.075	1.869	1.916	2.039	2.025	2.09
95% CBR after 4 days of immersion	%	87	53	39	39	61	53	72
2023 GTR Standings [10]		G3	I2	I2	I2	I2	I2	G3
Description		Silty or clayey (slightly clayey) gravel of alluvial origin, rocky Particle size distribution	Sands and gravels, clayey to very clayey	Sands and gravels, clayey to very clayey	Sands and gravels, clayey to very clayey	Sands and gravels, clayey to very clayey	Sands and gravels, clayey to very clayey	Silty or clayey (slightly clayey) gravel of alluvial origin, rocky Spread grain size distribution
GTR 2000 Classification [11]		B4	B6	B6	B6	B6	B6	B4
Description		Clayey gravel (low clay content)	Sands and gravels, clayey to very clayey	Sandy and gravelly, clayey to very clayey	Sands and gravels, clayey to very clayey	Sands and gravels, clayey to very clayey	Sands and gravels, clayey to very clayey	Clayey gravel (low clay content)

According to the GTR 2023 classification, the laterites from Keur Samba Kane and Lam-lam are classified as G3 and are well-suited for foundation or base layers due to their good particle size distribution, low plasticity, and high CBR values. The materials from Sindia, Ngoundiane, Tchicky, Yéba, and Kiniabour are classified as I2, and are therefore more suitable for layers subject to low loads. The Ngoundiane and Tchicky

laterites require improvement for use as a base layer, with that from Keur Samba Kane remaining the highest-performing material see. Previous studies on lateritic gravel materials in Senegal reported CBR values ranging from 15% to 31%, highlighting the variability of their bearing capacity depending on the material and treatment conditions [12]. Table 5.

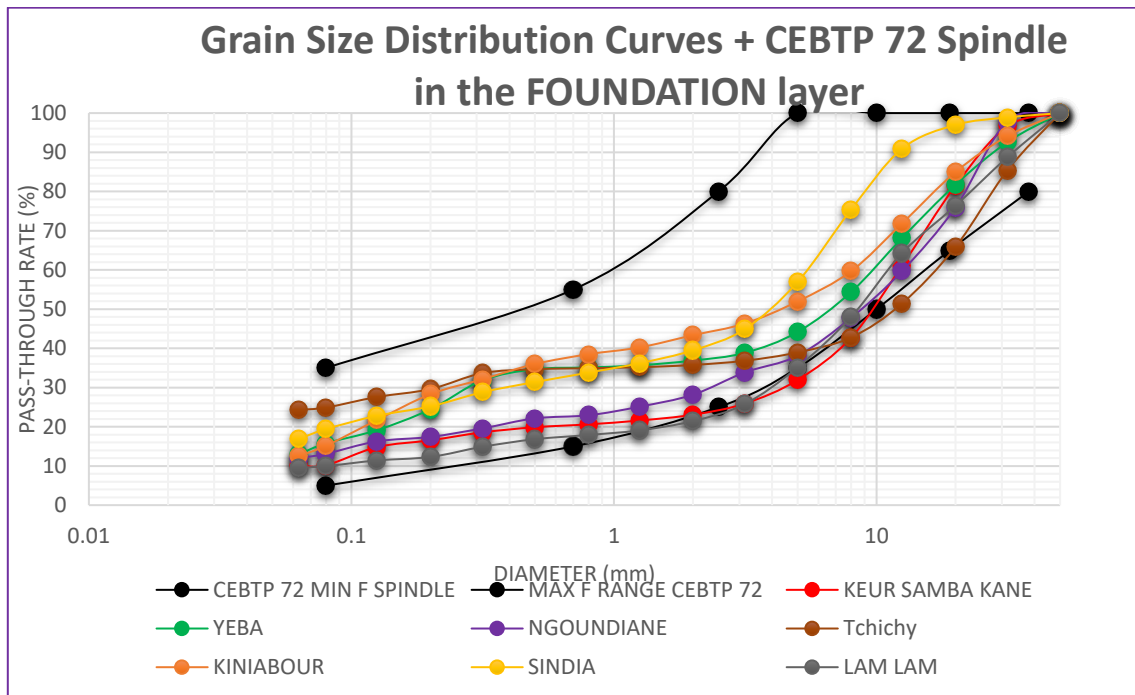


Figure 9 : Particle Size Distribution Curve + CEBTP 72 Base Course

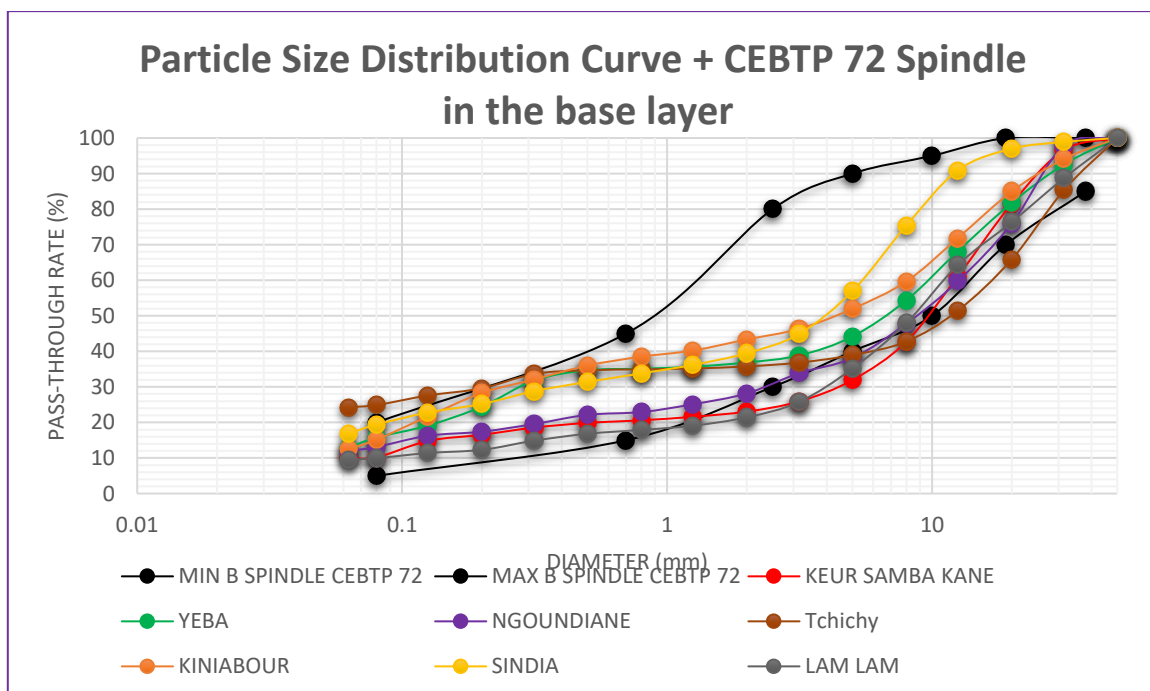


Figure 10 : Particle Size Distribution Curve + CEBTP 72 Spindle for Base Course

The particle size distribution curves generally comply with the limits of the range, except for certain materials from Keur Samba Kane (2–9 mm) and Tchicky (8–20 mm). Those from Yéba, Ngoundiane, and Sindia meet the

CEBTP 1972 specifications for foundation layers. In contrast, Keur Samba Kane, Kiniabour, and Tchicky fall slightly outside the range for base layers, see Figure 9 et 10.

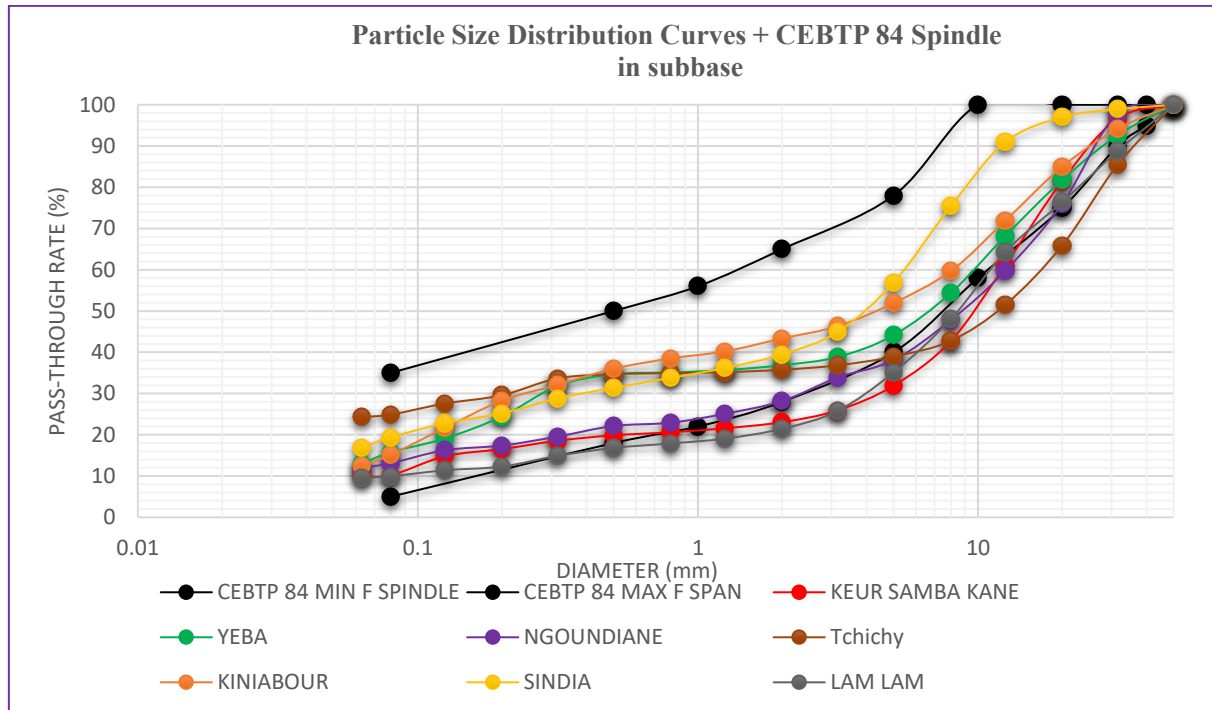


Figure 11 : Particle Size Distribution Curve + CEBTP 84 Range for Foundation Layer

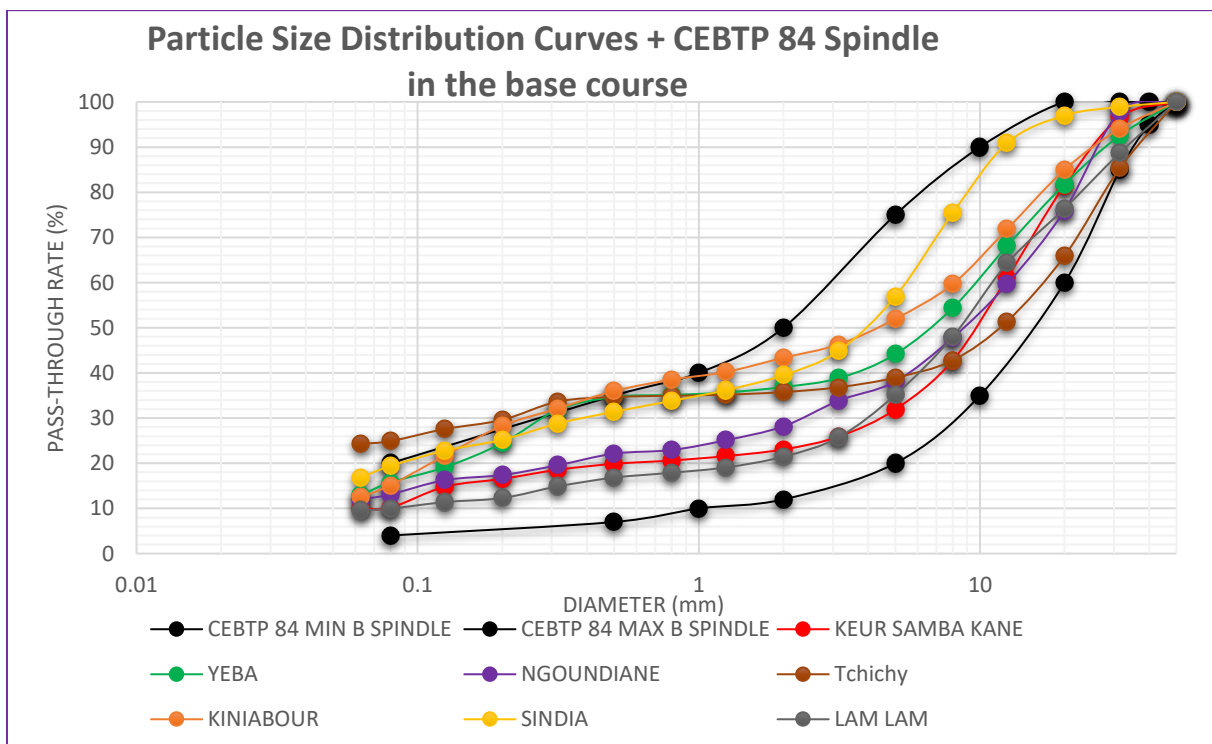


Figure 12 : Particle Size Distribution Curve + CEBTP 84 Range for Base Layer

The particle size distribution curves are generally compliant for the subbase layer, except for Ngoundiane, Tchicky, and Keur Samba, where certain fractions (>1 mm) fall outside the range and require adjustment. Sindia, Kiniabour, and Yéba fully comply

with the CEBTP standard. In the base layer, Keur Samba, Ngoundiane, Yéba, and Sindia remain compliant, while Tchicky shows a curve partially outside the range, indicating an excess of fines that needs to be corrected, see Figure 11 et 12.

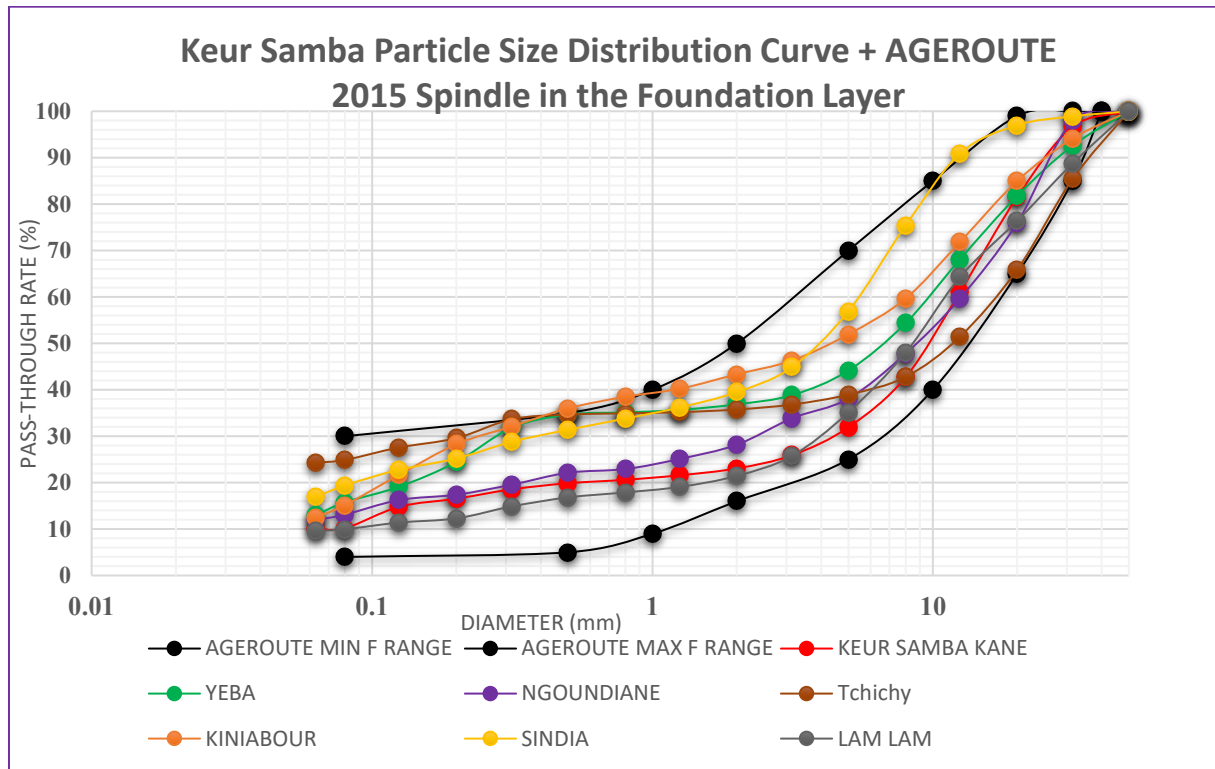


Figure 13 : Particle Size Distribution Curve + AGEROUTE 2015 Base Course

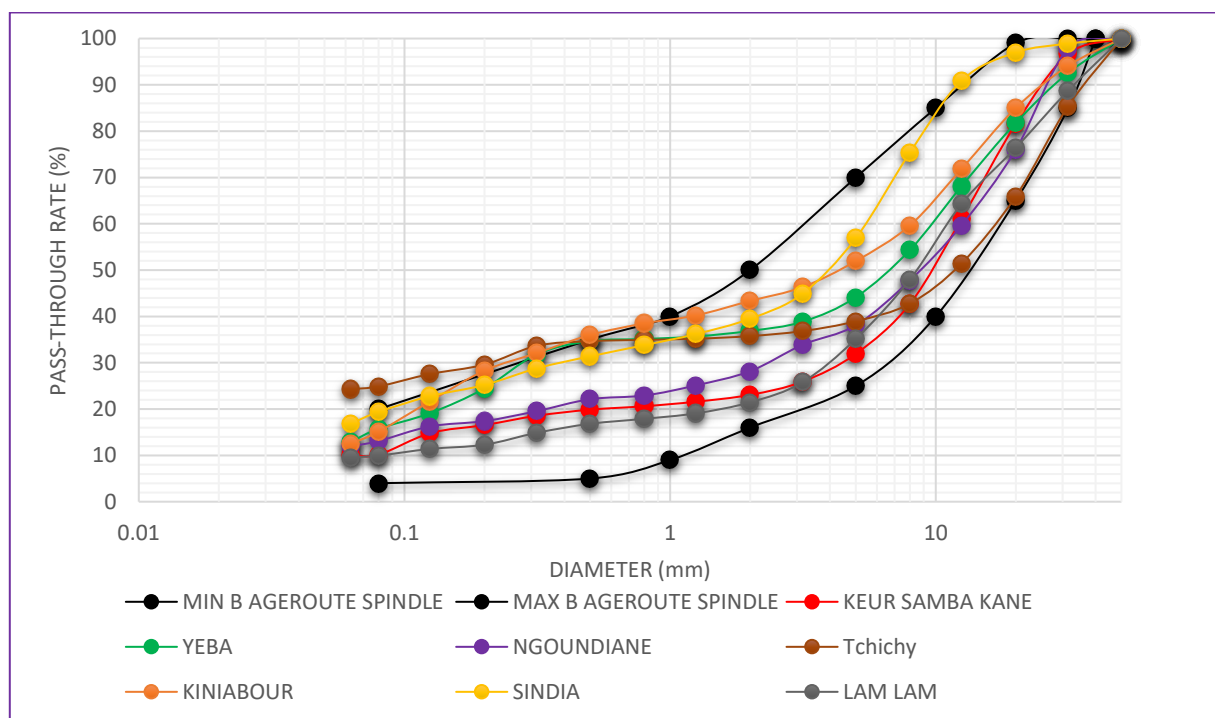


Figure 14 : AGEROUTE catalog particle size distribution + particle size distribution curves

The grain size results show that all samples fit within the AGEROUTE grading envelope for the sub-base layer. For the base course, all materials remain compliant, except for Tchicky, whose fraction under 0.4 mm falls outside the envelope. Overall, the materials meet the AGEROUTE 2015 standard requirements for both sub-base and base layers, see Figure 13 et 14,

CONCLUSION

The results of this study show that the lateritic materials from Keur Samba Kane and Lam-Lam are best suited for foundation and base layers, thanks to their well-balanced particle size distribution, low plasticity, and high bearing capacity (CBR > 70%). Materials from Ngoundiane and Tchicky, while acceptable for subgrades, nevertheless require treatment to meet the requirements for base layers. Overall, this study serves as a decision-making tool for the optimal selection of materials used in earthworks and pavement construction, thereby contributing to the enhanced durability of road infrastructure in the Thiès region. Finally, it highlights the need for a detailed cartographic study of quarries, which is essential for optimizing the exploitation and management of materials. With this in mind, we will soon announce a new article dedicated to the mapping of quarries in Thiès and its surroundings, aimed at improving earthwork and pavement construction.

Declaration by Authors

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Conflict of Interest: No conflicts of interest declared.

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