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# Study on the Improvement of Gravelly Laterites Using Mining Waste: Case of Phosphogypsum of Senegal

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## ABSTRACT

The objective of this study is to contribute to the valorisation of Senegalese phosphogypsum in road construction with the aim of improving the characteristics of lateritic gravel. Samples of laterite were taken in Ngoundiane and Tassette and physical and mechanical identification tests were carried out. An initial study on phosphogypsum and laterites was carried out, followed by the preparation of mixtures containing between 0 and 40% phosphogypsum with laterite. The results showed that phosphogypsum alone is not suitable for use as a base course. However, an optimal mixture of 30 % increases the fine content, reduces plasticity, and increases the CBR and compressive and tensile strengths. Nevertheless, phosphogypsum appears to be a granular corrector and allows for the judicious use of Tassette and Ngoundiane laterites as a base course.

***Keywords:*** phosphogypsum, recovery, road engineering, laterite

## I. INTRODUCTION

The mining industry is a key pillar of the economy in many countries which, like Senegal, have significant mineral resources. Indeed, the exploitation by ICS of calcium phosphate deposits in Taïba-Tobène has resulted in large deposits of phosphogypsum. Phosphogypsum is a by-product of phosphoric acid production, the main component of modern fertilisers. Phosphoric acid is obtained by attacking natural phosphate (consisting mainly of fluoroapatite and calcium carbonate) with sulphuric acid [1]. The production of one tonne of phosphoric acid generates 4.5 tonnes of phosphogypsum. With the ICS's phosphoric acid production capacity at 660,000 tonnes/year, we have a potential 2.970 MT of phosphogypsum waste per year that has been accumulating since 1984. Due to the polluting effects of the residual acid contained in phosphogypsum on groundwater, producing countries require all phosphoric acid production units to include a phosphogypsum processing unit in their projects. The storage of these mining and industrial waste products causes many environmental and land use problems, which raises the acute issue of their sustainable and economically profitable recovery in the road construction sector. Its recovery leads to environmental protection and minimises storage costs.

## II. LITERATURE REVIEW

Phosphogypsum generally takes the form of very fine, moist, yellowish sand. Phosphogypsum from ICS has a grain size ranging from 0 to 100 µm, with 30% of particles smaller than 40 µm (Diop et al., 2008).

Phosphogypsum has been the subject of several studies in Senegal and around the world. Indeed, the work of [2] has shown that the addition of phosphogypsum considerably accelerates the pozzolanic reaction of tuffs and induces a strength gain of nearly 60%, allowing tuffs to be used in road geotechnics. The chemical and mineralogical characteristics of phosphogypsum depend on the nature of the phosphate ore, the process (wet method) used, the age of the storage pile, any contaminants in the phosphogypsum and the efficiency of the production site. Its P2O5 content is generally less than 1% [3]. In general, phosphogypsum consists mainly of: 'hydrated' calcium sulphate, free and syncrystallised phosphoric acid, various soluble acids, numerous salts and heavy metals, and radioactive elements (possibly) [4].

Furthermore, the use of phosphogypsum as a road base activator is inspired by gypsonat, a welded gypsum marketed by Lambert Industrie that can be used as a substitute for lime as an activator at a dose comparable to slag gravel. However, the gypsonat technique only allows phosphogypsum to be used in small percentages [5]. Phosphogypsum can also be used as a binder. A mixture consisting of 91% ash, 4% lime and 5% gypsum is an excellent binder that can be used for foundation layer materials. Studies have shown that replacing gypsum with phosphogypsum in this mixture significantly improves performance and allows for much higher phosphogypsum dosages [5].

Laboratory studies on formulations using phosphogypsum and experimental road sections have been carried out in Texas [6] and Florida [7]. Among these roads are the municipal experimental sections in the city of La Porte, Texas, built with a 15 cm foundation layer treated with lime. The base layer is 20 cm of a mixture of phosphogypsum and 2.5 cm of Type II Portland cement.

Two experimental roads were built as part of the study conducted by [7]. The base layers of these roads consisted of compacted mixtures (phosphogypsum – soil) made on site. The roads were covered with an asphalt layer. The existence of groundwater tables enabled the authors to monitor groundwater quality. They report that the use of these materials does not significantly affect groundwater quality[1].

However, dry density is very sensitive to variations in compaction water content. Once the optimum water content is exceeded, there is a sharp drop in density, which can be problematic on site. Similarly, immersion causes the CBR index to drop ([8]; [9]).

## III. MATERIALS & METHODS

In order to characterise phosphogypsum and laterites, knowledge of several parameters is required. To this end, the following methodology is used, involving several laboratory tests.

### III.1. Sampling

In this study, three materials are examined: phosphogypsum, which straddles four local communities (Mboro, Darou Khoudoss, Taïba Ndiaye and Méouane). Ngoundiane laterite, located in the commune of Ngoundiane, in the Thiès region, 96 km east of Dakar. The Tassette borrow pits are located in the Thiès region, on the outskirts of the village of Tassette. However, bags of material were collected and sent to the laboratory for physical and mechanical identification tests.

### III.2. Laboratory tests

These tests concern phosphogypsum, Tasette laterite and Ndioundiane laterite. Initially, a complete survey was carried out on the phosphogypsum and then on the two laterites in order to guide the study. These tests were carried out on these samples in accordance with current standards.

- grain size analysis by sieving NF EN 933-1 and NF 94 257;
- Atterberg limits NF EN ISO 17892-12/A1;
- methylene blue test NF P 94-068,
- modified Proctor test NF EN 13286-2;
- CBR test NF EN 13286-47;
- compressive strength NF P 94-077
- tensile strength NF EN 13286-40.

### III.3. - Formulation of mixtures

The formulation of mixtures based on Tassette and Ngoundiane laterites allows the following percentages to be proposed:

Three mixtures were made for Tassette laterite:

- mixture M0: 100% laterite + 0% phosphogypsum,
- mixture M1: 75% laterite + 25% phosphogypsum;
- mixture M2: 70% laterite + 30% phosphogypsum;
- mixture M3: 65% laterite + 35% phosphogypsum.

For Ngoundiane laterite, four mixtures were made:

- mixture M0: 100% laterite + 0% phosphogypsum,
- mixture M1: 80% laterite + 20% phosphogypsum;
- mixture M2: 70% laterite + 30% phosphogypsum;
- mixture M3: 65% laterite + 35% phosphogypsum;
- mixture M4: 60% laterite + 40% phosphogypsum.

These mixtures were tested to assess their physical and mechanical performance.

## IV. RESULT AND DISCUSSION

The complete identification of the base materials yielded the results shown in Table 1 for phosphogypsum and Table 2 for the laterites of Tassette and Ngoundiane.

**Table 1. – Results of geotechnical characterisation tests on phosphogypsum**

| Tests | | Results |
|---|---|---|
| Water content w (%) | | 17 |
| Specific density | | 2.29 |
| VBS (g/100g) | | 0.36 |
| Atterberg limits | $W_L$ (%) | 38 |
| | $W_P$ (%) | 34 |
| | $I_P$ (%) | 4 |
| Particle size analysis | Dmax (mm) | 0.1 |
| | Passing through 2 mm size (%) | 100 |
| | Passing through 80 µm size (%) | 99 |
| | Passing through 63 µm size (%) | 95 |
| | Passing through 40 µm size (%) | 21 |
| Modified Proctor | $W_{Opm}$ (%) | 23 |
| | $\rho d_{Opm}$ (g/cm$^3$) | 1.397 |
| CBR (%) | | 34 |
| GTR classification | | A1 |

Table 1 shows the identification parameters for phosphogypsum. It shows that class A1 phosphogypsum is a very fine material with a 63 µm sieve pass of 95%. It is non-plastic with an Ip of 4 and has a very high optimum water content of 23%, a low optimum dry density of 1.39 and a CBR of 34. Phosphogypsum has an acceptable CBR for use in backfill and foundation layers. However, it's very low dry density, optimal water content and very high percentage of fines can be a disadvantage if the material is used in a humid environment, which can lead to a drop in bearing capacity. This excludes its use alone in road base layers.

The same tests were carried out on laterites, and the results are shown in Table 2.

**Table 2. Results of tests to identify the laterites of Tassette and Ndoundiane**

| Characteristics | | Tassette Latérite | Ngoundiane Latérite | Ageroute [10] specifications for foundation layer | Ageroute [10] specifications for base layer |
|---|---|---|---|---|---|
| **Particle size analysis** | % Ø< 50 mm | 100 | 100 | 100 | 100 |
| | % Ø < 2 mm | 26 | 23.44 | 16 – 50 | 16 – 50 |
| | % Ø < 80 µm | 14.9 | 13.04 | 4 – 30 | 4 – 20 |
| **Atterberg limits** | $W_l$ (%) | 59 | 42 | < 40 | < 35 |
| | $I_p$ (%) | 29 | 18 | < 20 | < 15 |
| **Modified Proctor** | $W_{opm}$ (%) | 13.4 | 9 | - | - |
| | $_{rd\ max}$ (g/cm$^3$) | 1.9 | 2.049 | ≥ 1.8 | ≥ 2.0 |
| **CBR** | ICBR (%) | 59 | 52 | ≥ 30 | ≥ 80 |
| **GTR Classification** | | B6 | B6 | B4, B5, B6 | |

This table shows the results of the identification characteristics of the Tassette and Ngoundiane laterites. It shows that these laterites are class B6 and have acceptable percentages of fines in the base and good bearing capacity for a foundation layer. However, Tassette laterite has an Ip of 29, which is not suitable for use in foundations and bases, unlike Ngoundiane laterite, which has an Ip of 18, suitable only for foundations. Furthermore, its dry density meets the specifications for a base layer. Given the limitations of these laterites for use in base layers, an attempt to mix phosphogypsum with laterite is being considered in order to improve the performance of these laterites with phosphogypsum by utilising its fine, powdery soil characteristics.

## IV.1. Influence of phosphogypsum on the particle size distribution of laterites

Particle size analysis by sieving carried out on mixtures of Tassette and Ngoundiane laterites in accordance with standard NF EN 933 makes it possible to determine the weight proportions of grains of different sizes (Figure 1 and 2). The following mixtures were made using these laterites.

For Tassette laterite, three mixtures were made:

- mixture M0: 100% laterite + 0% phosphogypsum,
- mixture M1: 75% laterite + 25% phosphogypsum;
- mixture M2: 70% laterite + 30% phosphogypsum;
- mixture M3: 65% laterite + 35% phosphogypsum.

For Ngoundiane laterite, four mixtures were made:

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- mixture M3: 65% laterite + 35% phosphogypsum;
- mixture M4: 60% laterite + 40% phosphogypsum.

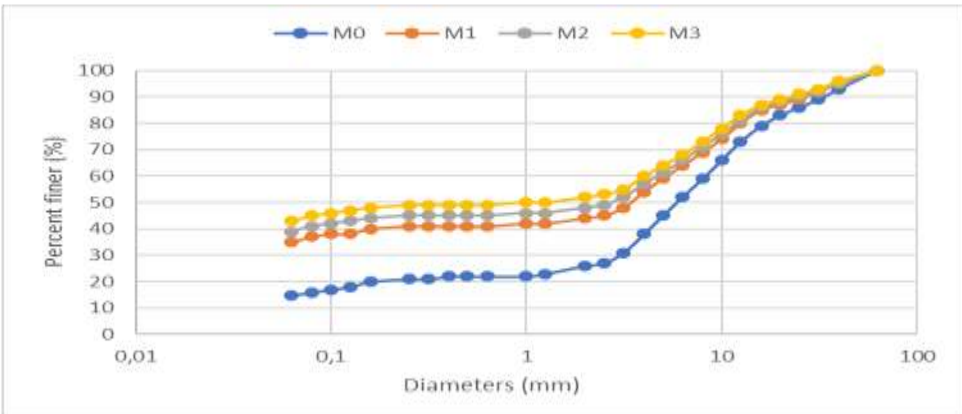


**Figure 1 Evolution of particle size depending on the mixtures on the Tassette laterite**

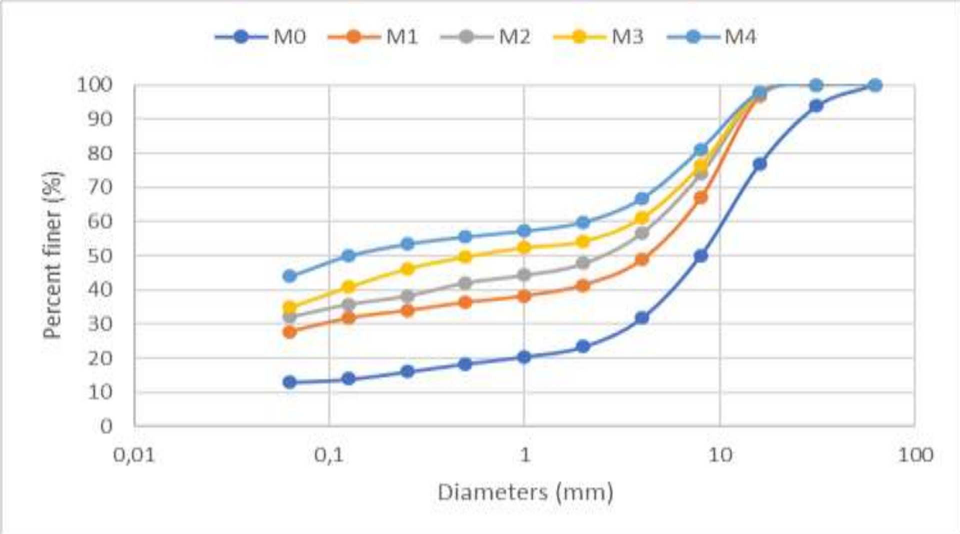


**Figure 2 Evolution of particle size depending on the mixtures on the Ngoundiane laterite**

These curves show that the percentage of fines (passing through a 0.063 mm sieve) increases gradually with the percentage of phosphogypsum. This increase in the percentage of fines varies between 14.8 and 42.9 % for Tassette laterite and between 13.04 and 43.92% for Ngoundiane laterite. This increase in the percentage of fines has a significant influence on the initial M0 material, which tends to become a fine-grained M4 or M3 laterite. This increase can be explained by the addition of phosphogypsum, which is a very fine material. Furthermore, this increase in fines becomes optimal with a phosphogypsum percentage of 30% for M2, giving it a dense structure. With this percentage, the behaviour of the material is governed by its coarse fraction, whose voids are gradually filled by the fine fraction of phosphogypsum, giving it its high density. A proportion of approximately 30% fine particles allows for optimal arrangement [11]. Above this percentage, the fine particles gradually take over from the coarse fraction, giving it a fine structure.

### IV.2. Influence of phosphogypsum on the plasticity index of laterites

Clay content was assessed using the plasticity index (Figures 3 and 4). It decreased from 19 to 13 for Ngoundiane laterite and from 29 to 20 for Tassette laterite, representing a decrease of between 6 % and 9 %.

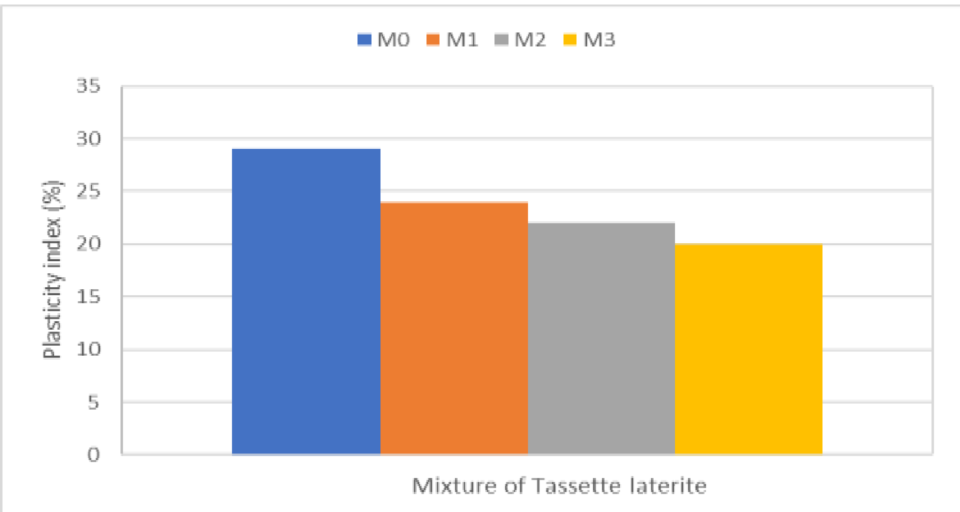


**Figure 3. Evolution of the plasticity index as a function of mixtures on the Tassette laterite**

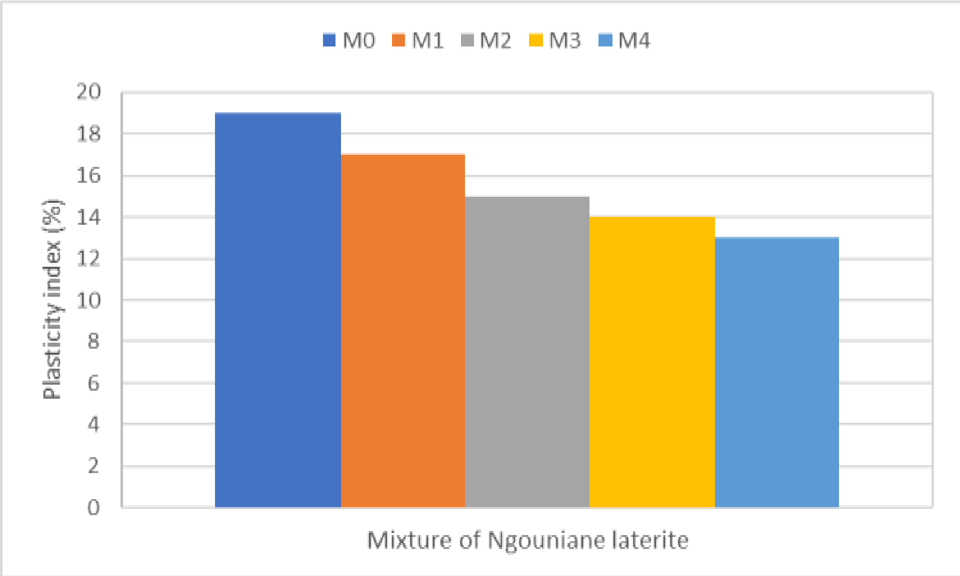


**Figure 4. Evolution of the plasticity index as a function of mixtures on the Ngoundiane laterite**

This decrease of the plasticity is due to the non-cohesive structure of phosphogypsum and its low plasticity of 4%, an increase in which reduces the plasticity of both laterites. However, phosphogypsum has corrected the clay content of these two laterites and validates the clay content of the Tassette laterite as a foundation layer and that of Ngoundiane as a base layer.

### IV.3. Influence of phosphogypsum on the CBR of laterites

The figures 5 and 6 show the evolution of the CBR as a function of mixtures for the laterites of Tassette and Ngoundiane.

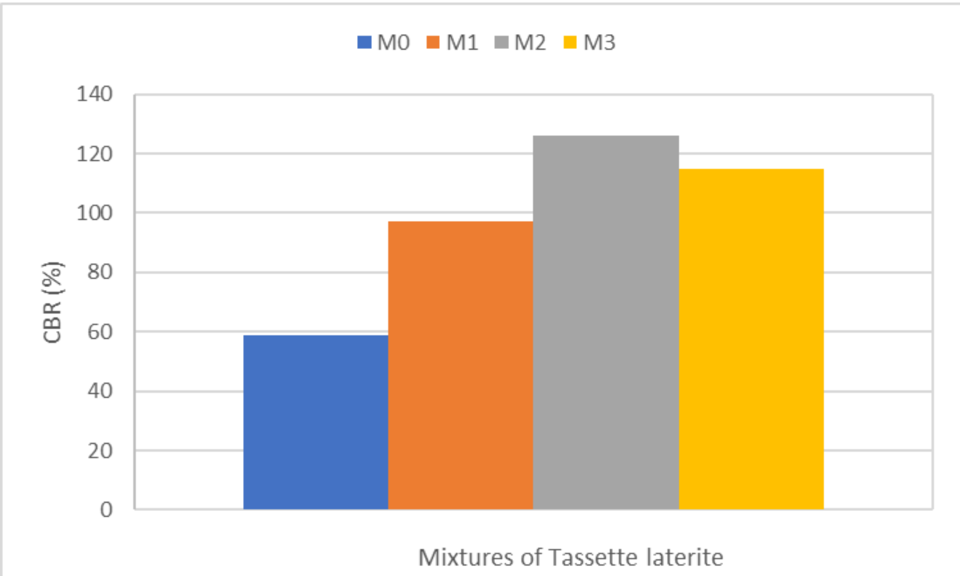


**Figure 5 Evolution of CBR according to mixtures for Tassette laterite**

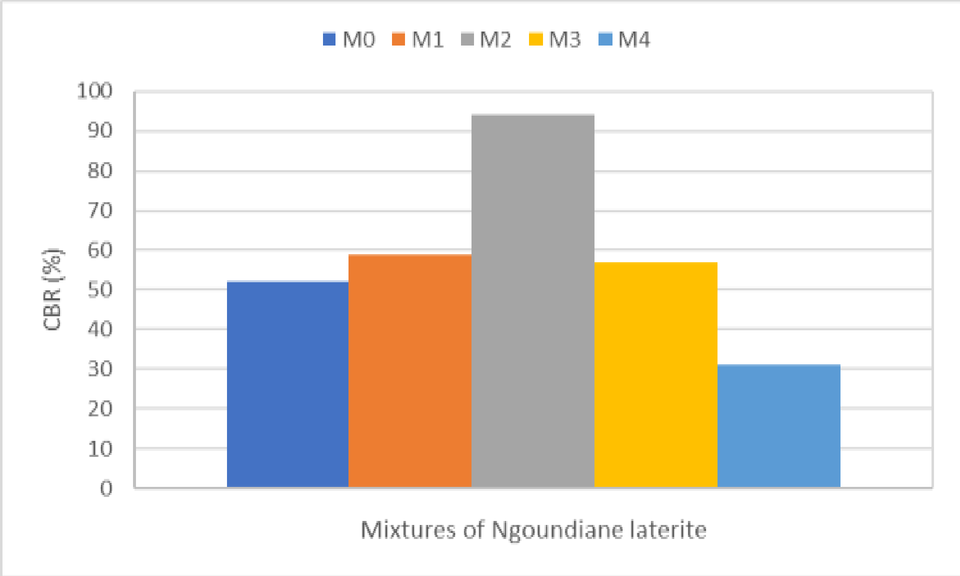


**Figure 6 Evolution of CBR according to mixtures for Ngoundiane laterite**

This initial increase in CBR is due to the increase in the contact surface area of the gravelly laterite grains as the voids fill up, reaching a maximum at M2. When all the voids are filled, the excess of fine particles facilitates relative movement between the large particles of the laterites, leading to a decrease in the CBR (M3 and M4) for Ngouniane laterite and M3 for Tasette laterite. This same behaviour is observed in both laterites and obeys a mixture of 30% phosphogypsum. Thus, for Tassette laterite, the CBR varies from 59 to 126% and from 52 to 94% for Ngoundiane laterite for mixtures from M0 to M2. These represent increases of 67 and 42 respectively on the initial CBR, which gives these laterites a CBR suitable for a base course. Phosphogypsum has corrected the particle size distribution of the laterites, giving them a dense structure, and has also reduced their plasticity and increased their CBR.

The rigid nature of the phosphogypsum mixtures with laterite and the suitability of Ngoudiane laterite for use as a base course prompted us to study compressive and tensile strength tests. These were carried out on the mixture with 30% phosphogypsum, which represents the optimal mass percentage of phosphogypsum. The results show that this laterite gives an Rc value of 20.215 bar, an Rt value of 2.525 bar and an Rc' value of 4.528 bar. However, there are still no reference values for phosphogypsum laterites in Senegal to validate these strengths, but they are close to the values indicated for cement laterites.

## V. CONCLUSION

The study shows that phosphogypsum as a mining waste product can improve the physical and mechanical characteristics of the laterites of Tassette and Ngoundiane. Phosphogypsum modifies the geotechnical properties of lateritic materials and makes them suitable for certain road uses, with an optimal mass percentage of phosphogypsum presenting the best CBR bearing capacity of 30%. It acts as a granular corrector, increasing the amount of fines, reducing plasticity and increasing the CBR and compressive and tensile strengths of laterites. It has enabled better use of Tassette and Ngoundiane laterites as base courses.

***Declaration by Authors***

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