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# The Flint: A New Alternative Material for Flexible Pavements in Senegal

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**Abstract** The objective of this work is to study flint as an alternative material for flexible pavements. Samples were taken in Mboro and identification tests were carried out. The results showed that flint has good intrinsic characteristics and good compaction behaviour. In its raw state, flint has a density value of 2.2 and a CBR of 194. When litho-stabilized with laterite, the CBR increases by 19% for a 30% flint content. In bituminous surfacing, the Marshall test gives stability values ranging from 1151 to 1350 kg and creep ranging from 2.72 to 2.24 mm. The Duriez test gives an R'c/Rc value of 0.76 and a void percentage of 7.83% at 80 rotations for the PCG test. The use of flint in hydraulic concrete paving stones provides good tensile strength, which can reach up to 5.9 MPa at 28 days depending on the cement dosage and grain size used. This makes flint an attractive material for road construction and means it can be used as an alternative material for flexible pavements in Senegal.

***Keywords:*** *flint, alternative material, strength, flexible pavement*

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## 1. Introduction

In Senegal, laterite has long been the material of choice for road construction. This material has the advantage of being found in very large deposits throughout the African tropical zone, but it is also relatively easy to extract [1]. Today, given the increasing scarcity of high-quality laterite, road construction companies are resorting to improving or stabilizing these lateritic materials. These processes tend to increase the cost of road projects. In response to this situation, research has been conducted in Senegal to find substitute materials for laterite and basalt. However, studies by [2] reveal that 0/31.5 basalt aggregate was used as a foundation layer at Colobane on the Patte d'Oie-Malick Sy motorway. Furthermore, for our surface layers, Diack basalt has long been the most recognized and widely used material for the formulation of high-quality asphalt mixes. However, the Diack deposit is running out.

In view of this situation, studies have been carried out with the aim of finding other materials capable of replacing basalt. These materials include Bakel quartzite, Mansadalla granodiorite in the Kédougou region (already used in the formulation of gravel-asphalt) and Mboro flint, currently used in the manufacture of hydraulic concrete and under study for possible use as aggregate in asphalt concrete [3].

However, Senegal has other materials that could be used as an alternative for building low-traffic road structures. These materials include flint, which is a highly siliceous material that occurs in the form of nodules or grouped in more or less horizontal layers in phosphate deposits. These are residues from phosphate mining in Taïba in the Thiès region. On average, they are composed of 91% flint, 6% hardened phosphate and 3% fines with phosphate and clay elements [4]. It is not usually used in road construction due to its flattened shape and fairly smooth surface. However, attributing mechanical performance to flint mainly on the basis of measurements is reductive and not always satisfactory. This is why we are studying the mechanical performance of this flint in order to see its potential for use in flexible pavements.

Several studies have been carried out on these flints in Senegal. The work of [5] showed that flint has low bearing capacity in its raw state, but that adding cement considerably increases its bearing capacity. The work of [6] shows that the values obtained for the bituminous mixture in flint without dope meet the requirements for compactness, creep and stability. However, this mixture cannot be used as a wearing course due to its low immersion/compression strength ratio. Improving the mixture with filler results in stability, creep, compactness and immersion/compression strength ratio values that exceed the required standards. The work of [7] shows that the results obtained are usually satisfactory for basalts, unlike those for flint, which show some non-compliance with technical specifications, particularly in terms of performance in the Duriez test and also in terms of intrinsic properties such as resistance to fragmentation, wear resistance and sand equivalent value. According to them, the BB mixture of flint is more economical than that of basalt, unlike the GB mixture of flint, which is more expensive than that of basalt due to the high rate of bitumen used for flint.

## 2. Methodology

The study involves taking samples of flint. This is obtained from the rejects of the pre-treatment plant, with an estimated particle size distribution [8]. The mined ore is delivered by 100-tonne lorries or dumpers in the form of 0/2000 mm granular aggregate to screen no. 1, also known as a scalper or destoner, which subjects it to 20-bar water jets to separate the blocks from the mineral particles. Blocks larger than 200 mm are removed from the cells, where they are picked up by dumpers and placed in small scattered piles. The rest of the material (0/200 mm) continues the desliming process to screen no. 3, where, after being subjected to water jets at 10 bar, it is separated into a mineral pulp (d < 25 mm) destined for the washing station and a residue transported by a waste conveyor to a spoil tip [4].. These samples were then characterized in the laboratory and formulation studies were carried out (Figure 1). The first study investigated the possibility of using flint as a GNT in its raw state and in a litho-stabilized state as a base layer. The second study focused on its potential for use on the surface. To this end, a study was carried out on the formulation of bituminous concrete and hydraulic concrete for use as paving stones.

Various granular fractions were sampled at the Mboro quarry and are being tested to determine the intrinsic and manufacturing characteristics of the material. These tests include granularity, shape, density, cleanliness and resistance to fragmentation and wear in accordance with standards.

- Grain size analysis (NF EN 933-1);
- Micro Deval (EN 1097-1);
- Los Angeles (EN 1097-2);
- Determination of specific weight (NF EN 1097-6);
- Apparent density (NF EN 1097-3);
- Sand equivalent test (EN 933-8);
- VBS (NF EN 933-9);
- Determination of the coefficient of flattening (EN 933-10).

The results of these tests are recorded in Table 1.

Table 1 shows that flint is clean and its shape is not flattened. It also has good resistance to wear and fragmentation. These interesting parameters encourage us to study the performance of this material for use in flexible pavement layers.

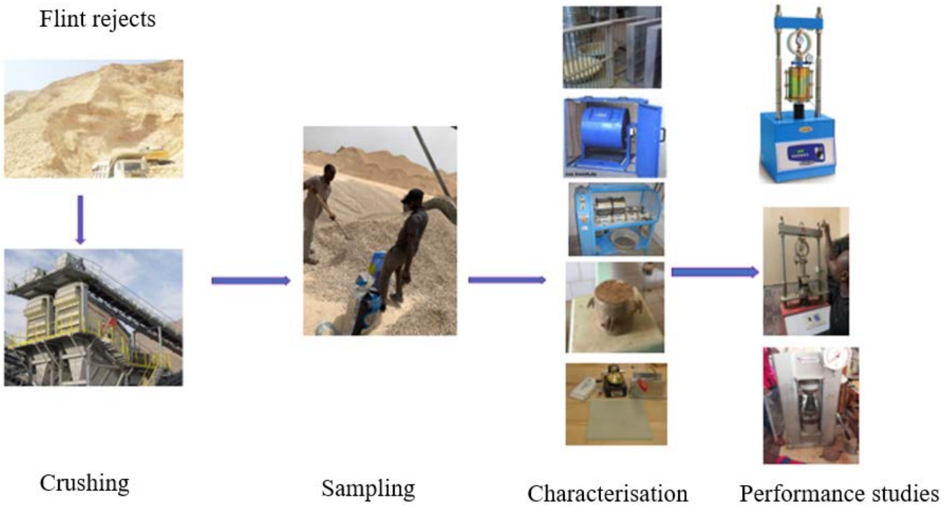


**Figure 1.** Methodology for studying flint

**Table 1. Intrinsic and manufacturing characteristics of flint**

| Geotechnical characteristics | (Units) | Granular classes (mm) | | | Specifications | Compliance |
|---|---|---|---|---|---|---|
| | | Flint 0/3 | Flint 3/8 | Flint 8/14 | | |
| VBS | (g/100g) | 0.7 | - | - | < 2 | compliant |
| coefficient of flattening | (%) | - | 18.88 | 15.67 | ≤20 | compliant |
| Los Angeles (LA) | (%) | - | - | 22.88 | < 25 | compliant |
| Micro Deval (MDE) | (%) | - | - | 18.2 | < 20 | compliant |
| LA + MDE | (%) | - | - | 41.08 | < 45 | compliant |

# 3. Results and Discussion

## 3.1. Use of Flint as GNT

Flint is studied here as a GNT in a base course. The GNT used here is GNT B, obtained by mixing several granular size fractions. The formula for this mixture is determined by particle size analysis with adjustment so that its particle size curve fits within the specification range for the 0/20 mm class according to standard NF EN 933-1. For this study, the best formula for the mixture obtained from the respective fractions 0/3, 3/8, 8/16 and 8/25 mm, for a GNT B of class 0/20, is as follows: 40% of the 0/3 mm fraction, 25% of the 3/8 mm fraction, 30% of the 8/16 mm fraction and 5% of the 8/25 mm fraction.

Proctor and CBR tests were carried out on this GNT B to assess its suitability for use as a base course and foundation course. The results of this study are shown in Table 2.

Table 2 shows the compaction and puncture resistance parameters for flint in its raw state. It shows that the compaction characteristics are consistent for both base layers and foundations. Furthermore, the CBR value of 194 shows that this material has good puncture resistance and can withstand high loads. This is due to the presence of 60 to 70% chalcedony and 40 to 30% opal in the flint. These minerals are varieties of silica in flint, which has a hardness rating of 7 on the Mohs scale.

## 3.2. Use of Flint in Lithostabilization

For lithostabilization, laterites taken from the Lam-Lam quarry were studied. They are grouped into two mixtures called LAM1 and LAM2.

- The LAM1 mixture consists of samples with CBR indices below 60.
- The LAM2 mixture consists of samples with CBR indices above 60.

The results of these mixtures are recorded in Table 3.

These mixtures have plasticity indices of 13.24 for LAM2 and 15.27 for LAM1. The latter is higher than the limit value proposed by the CEBTP. The bearing capacities obtained do not allow for use as a base course. Indeed, the CBR at 95% OPM is equal to 61.0 and 56.2, which is lower than the value of 80 prescribed by CEBTP 1984. However, the use of these laterites as a base course requires correction. Lithostabilization with flint is therefore recommended for the compliant use of these laterites as a base course.

The laterites are mixed with flint in percentages ranging from 0 to 40%. The results are shown in Figure 2 and Figure 3.

**Table 2. Characteristics of flint**

| Tests | | GNT of flint | Specifications | Compliance |
|---|---|---|---|---|
| Modified Proctor | $\rho_{OPM}$ (g/cm$^3$) | | > 1,8 (foundation) | Compliant |
| | | 2,02 | > 2 (base) | |
| | $W_{OPM}$ (%) | 8,4 | - | - |
| CBR, at 95 % de l'OPM (%) | | 194 | > 30 (foundation) | Compliant |
| | | | > 80 (base) | |

**Table 3. Characteristics of the LAM1 and LAM2 mixtures**

| Sample | Grain size distribution (%) | | | PlasticityIndex ($I_P$) | Modified Proctor | | $I_{CBR}$ à 95% OPM |
|---|---|---|---|---|---|---|---|
| | 0.08 mm | 2 mm | 10 mm | | $W_{OPM}$ (%) | $\rho_{dopm}$ (g/cm$^3$) | |
| LAM1 | 15.40 | 38.40 | 78.90 | 15.27 | 9.3 | 2.098 | 61.0 |
| LAM2 | 13.40 | 54.20 | 85.50 | 13.24 | 8.5 | 2.170 | 56.2 |
| Specification | Base layer | | | ≤ 15 | - | ≥ 2 | ≥ 80 |

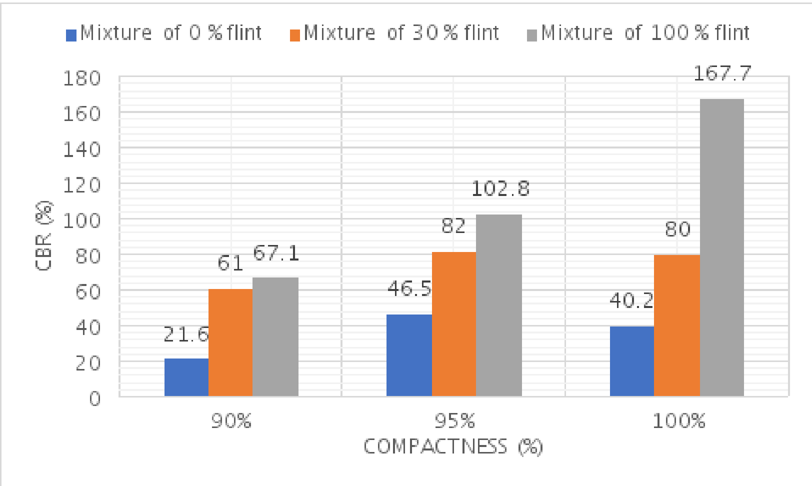


**Figure 2.** Evolution of CBR as a function of flint percentage and compactness for LAM1

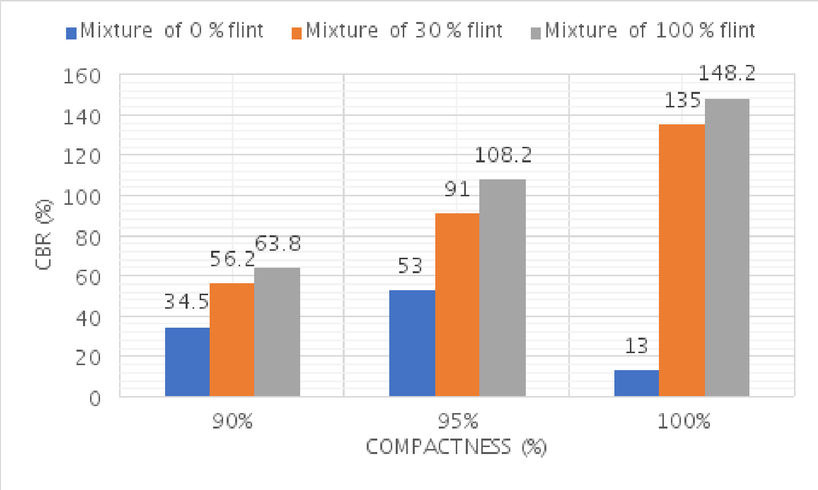


**Figure 3.** Evolution of CBR as a function of flint percentage and compactness for LAM2

Figure 2 and Figure 3 show that the percentage of flint increases gradually with the CBR value. This value rises from 61% to 82% at 95% of the OPM for LAM1 and from 56.2% to 91% for LAM2, representing an increase of 21% to 35% for LAM1 and LAM2 respectively. This can be explained by the phenomenon of densification of the granular skeleton through the addition of flint, which increases the rigidity of the mixture. The optimum percentage is obtained at 95% with a flint content of 30%.

In addition, the plasticity limit decreased from 15.27% for raw laterite to 11.37% for the LAM1 mixture with 30% flint and finally to 11.18% for the MLA1 mixture with 40% flint.

The plasticity index gradually decreases from 13.24% in the raw state to 11.90% for the LAM2 mixture with 30% flint and finally to 11.57% for the MLA2 mixture with 40% flint.

This technique, using flint, makes it possible to correct the grain size and clay content of laterites that are suitable for use as a base layer.

## 3.3. Use of Flint As Aggregate in Surface Course Asphalt Mixes

For use in asphalt mixes, a 0/14 asphalt concrete mix was produced. The formula consists of 42% 8/14, 23% 3/8 and 35% 0/3 with a 35/50 bitumen content of 6.1% (Figure 4).

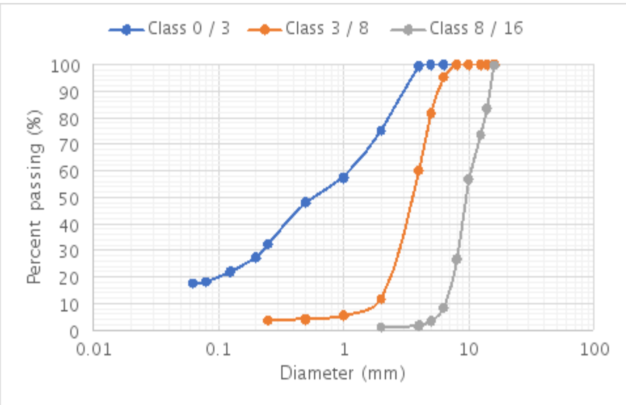


**Figure 4.** Grain size distribution curves for the various grain classes

Marshall, Duriez and PCG tests were carried out to assess their mechanical performance (Figure 5, Figure 6 and Figure 7).

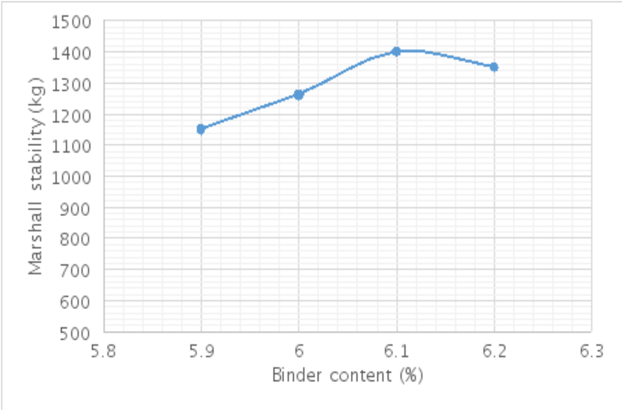


**Figure 5.** Evolution of Marshall stability according to bitumen content

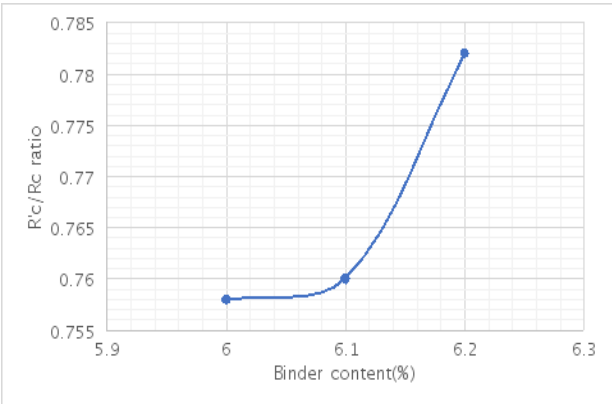


**Figure 6.** Evolution of the R'c/Rc ratio according to bitumen content

Figure 5 and Figure 6 show the evolution of Marshall stability and the compression-immersion relationship according to binder content, respectively. They show an increase in these parameters as the bitumen content increases. Marshall stability varies from 1151 to 1350 kg. The Duriez test gives an R'c/Rc value of 0.76. However, the PCG test gives a void percentage of 10.7% at 80 rotations. In addition, we note a problem with the compactibility of the mixture. This is due to the surface condition of the flint, which is very smooth, making its adhesion to the bitumen problematic. Two techniques were used: the use of a binder and the addition of 0/3 basalt.

An Iterlen 400 adhesive binder of 1‰ to 2‰ was used to monitor the evolution of water sensitivity (Figure 5).

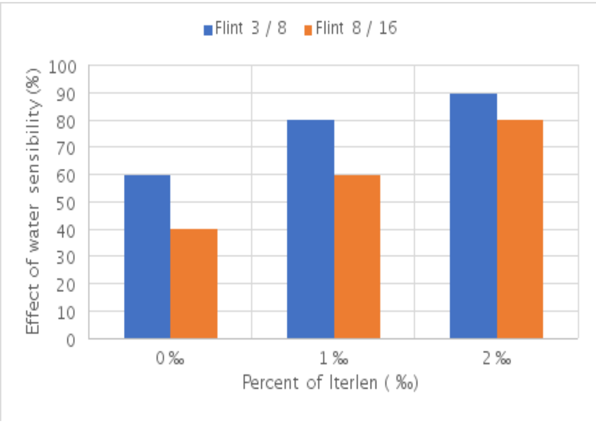


**Figure 7.** Effect of Iterlen on the water resistance of asphalt mix

Figure 7 shows that adding Iterlen gradually reduces sensitivity to water and increases the adhesion between flint and bitumen. Although effective, this method remains costly, so the natural method is used for the rest of the study. This technique consists of adding 0/3 basalt, in this case 4%, to the 6.1% bitumen mixture in order to facilitate adhesion between the bitumen and the flint. For the PCG test, the results show that adding 0/3 basalt significantly reduces the void percentage at 80 gyrations from 10.7% to 7.83% and increases compactness from 82.32% to 92.17% (Figure 8).

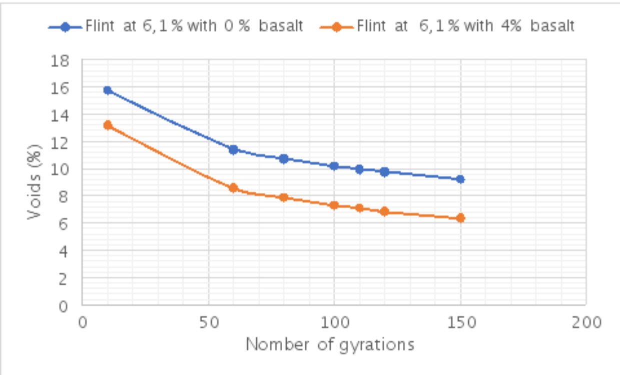


**Figure 8.** Change in the percentage of voids according to the number of gyrations

Basalt is a powdery material that forms a rough interface between bitumen and flint, thereby facilitating adhesion between the two materials. However, to ensure the durability of this product, the road surface must be protected from water to prevent it from stagnating on the road.

### 3.4. Use of Flint As Concrete Aggregate for Paving Stones

Flint is also used as a road surface covering. Paving stones were produced using different mix ratios and their tensile strength at 28 days was analyzed. The composition used was 35% sand, 6% 3/8 flint and 59% 8/16 flint mixed with 350, 400 and 450 kg of cement for class 0/16 and 46% sand and 54% 3/8 flint for class 0/8. Tensile strength tests were carried out to monitor the mechanical performance characteristics of the paving stones at 28 days (Figure 9).

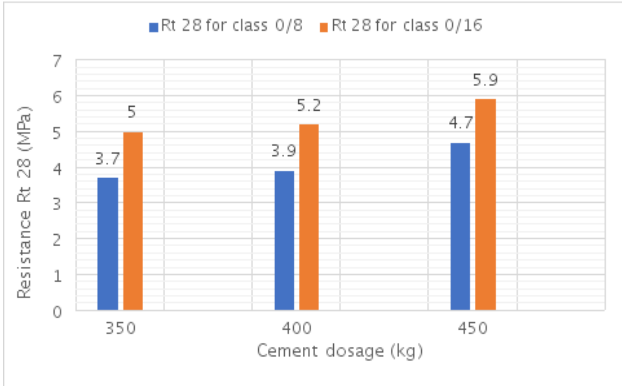


**Figure 9.** Tensile strength measurements at 28 days for the class 0/8 and 0/16 hydraulic concrete mix

The splitting tensile strength of the paving stones at 28 days increases from 3.7 MPa to 4.7 MPa when the cement dosage varies from 350 kg to 450 kg for class 0/8 and from 5 to 5.9 MPa for class 0/16 flint. These tensile strengths are well above the limit value of 3.6 MPa required for paving stones used in road surfacing.

## 4. Conclusion

The study of this formulation based on mining waste shows that flint has good intrinsic characteristics. In its raw and litho-stabilized state, flint is suitable for use in road bases. For use in surfacing with a binder content of 6.1%, the Marshall and Duriez tests are conclusive. The PCG test is valid after correction of the bitumen-flint interface with 0/3 basalt. The use of dope gives good results but increases the cost of the formulation. Flint has satisfactory values for use in paving stones for surfacing. This study therefore shows that flint mining waste can be an alternative to basalt in the base and surface layers for flexible pavements..

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