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Sustainable approach to road construction: Utilizing sand asphalt and lateritic gravel for the base course of the Daloa–Issia Road (Cote D'ivoire)

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Abstract

The scarcity of natural aggregates necessitates new solutions for sustainable road construction. This work evaluates the feasibility of reusing a blend of degraded sand asphalt and lateritic gravel (MESAGLA), sourced from the Daloa–Issia road (Côte d'Ivoire), as a base course material. Geotechnical tests (grading curve, Atterberg limits, Modified Proctor, CBR) were conducted to characterize this material. The results show that MESAGLA has a particle size distribution well-suited to road specifications and a satisfactory plasticity index (PI = 18.88). The optimum water content (6.21 %) and the maximum dry density (2.30 t/m^3) indicate good compaction conditions. However, the measured CBR value (59 at 99 % compaction) remains insufficient for direct use in a base course, in accordance with current standards (CBR ≥ 80). It is therefore necessary to resort to hydraulic binder stabilization or the addition of crushed aggregates to improve its mechanical performance. This approach illustrates the potential for utilizing recycled materials within a perspective of the circular economy and sustainability in highway engineering.

Keywords: Sustainable road construction; Sand asphalt; Lateritic gravel; Utilization (or Valorization)

1. Introduction

The preservation of natural resources has become a global priority. In this context, the Building and Public Works (BPW) sector is shifting toward the use of sustainable alternatives to natural materials. The recycling of demolition materials, for example, helps to preserve and conserve the natural aggregates necessary for construction sites (ARABI AND BERREDJEM, 2011). The Building and Public Works (BPW) sector, and particularly road construction, is a major consumer of aggregates. CABRERIZO (2019) highlights that roads are composed of 80 to 90% aggregates. However, sourcing materials that comply with technical requirements can prove difficult and costly, especially when borrow areas are far from the construction sites. Faced with these challenges, the reuse of materials from old road infrastructures constitutes a relevant solution. C&D waste often exhibits technical properties favorable to its use as a substitute for natural aggregates in road sublayers (MKAHAL, 2021). Other waste materials, such as recycled plastics, have also been successfully tested in this field (BOUDLAL et al., 2029); (NDEPETE et al., 2022). Another option would be the utilization of stripped pavement layers, which offers a promising avenue for the construction of new infrastructure. It is within this perspective that the present work is situated. It aims to evaluate the possibility of reusing degraded sand asphalt and the underlying lateritic gravel layers from the Daloa–Issia road (center-west of Côte d'Ivoire) to constitute the subbase layer of a new pavement. The study consists of determining the physical and mechanical properties of the sand asphalt–laterite mix with the goal of its use in the base course of the rehabilitated road.

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2. Materials and methods

2.1. Study Area

The study area is located on a section of the road connecting the town of Issia to that of Daloa, both located in the center-west of Côte d'Ivoire, specifically in the Haut-Sassandra region. Figure 1 illustrates the map of the study area. This sector rests on a deep ferrallitic soil, red to ocher in color on the surface, often gravelly or thick granular (DURAL, 1993). The studied section covers 25 km of road, including 20 km in Daloa and 5 km in Issia, with a pavement width of 7.4 m. The shoulder has a width of 2 × 1.5 m in rural areas and 2 × 2 m when crossing villages. The area is located between the coordinates:

- Latitude: 6°49'11'' and 6°87'70'' North
- Longitude: 6°45'02'' and 6°58'58'' West

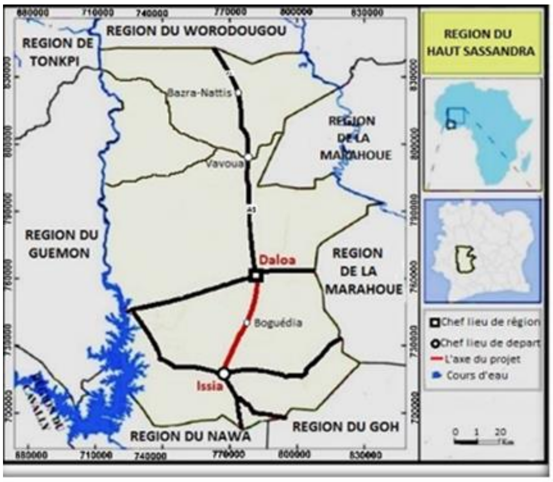

Figure 1 Map of the Haut-Sassandra Region

2.2. Raw Materials

2.2.1. Unprocessed Sand Asphalt – Lateritic Gravel Mix (MESAGLA)

Sand asphalt is a road material consisting of a mixture of sand and bitumen, used for the surfacing of the existing pavement. It was collected together with the lateritic gravel constituting the underlying layers, to a depth of 25 cm, using a pavement recycler (Figure 2a). After extraction, the mix was crushed and homogenized in the machine (Figure 2b).

(a) (b)

Figure 2 Extraction of the mixture: (a) Pavement recycler (b) Sand asphalt and lateritic gravel

2.2.2. Characterization Equipment

The characterization of the materials (unprocessed and stabilized mix) utilized the following equipment (Figure 4):

- A set of sieves (or A sieve column)
- An oven
- Molds (Proctor and CBR)
- Hammers (Proctor and CBR)
- A Casagrande device (or A Casagrande liquid limit device)
- A CBR press
- A balance (or A scale)

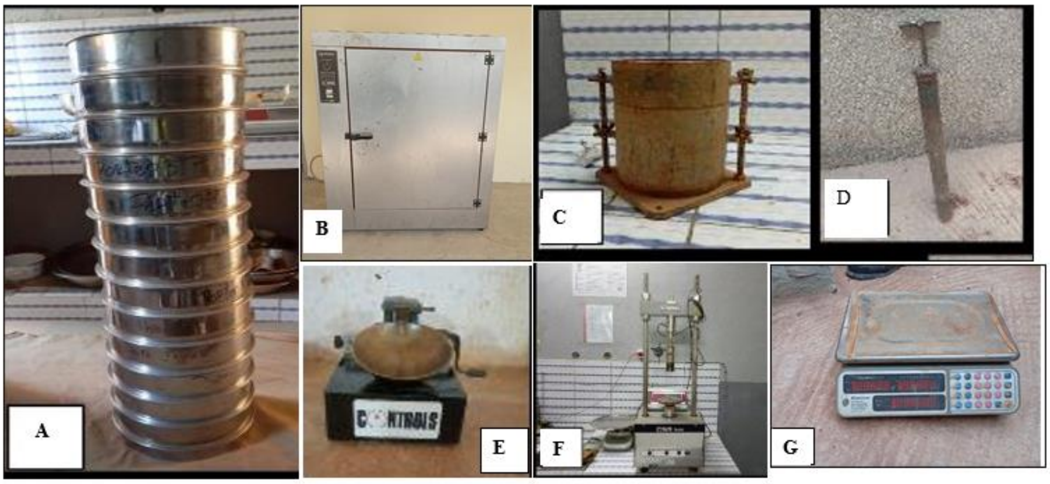

Figure 3 Characterization Equipment (A) Set of sieves, (B) Oven, (C) Proctor and CBR Molds, (D) Proctor and CBR Hammer, (E) Casagrande Liquid Limit Device, (F) CBR Press, (G) Scale

2.3. Méthods

The tests were first carried out on MESAGLA to determine its properties, and then on MESAGLAS to evaluate the effect of cement stabilization.

2.3.1. Détermination de la teneur en eau

The determination of the material's water content is necessary because it quantifies the water initially contained in the material upon sampling. This involves drying the material in the oven for 24 hours. This operation allows for the determination of the mass of water contained in the material m_w by the difference in masses before and after drying. The water content of the material is obtained by the following relation:

$$\omega\ (\%) = \left(\frac{m_h - m_s}{m_s}\right) \times 100 \qquad \textbf{(1)}$$

Avec ω (%) **:** Water Content, m_h **:** wet mass of the sample and m_s **:** dry mass of the sample (after oven-drying).

2.3.2. Sieve Particle Size Analysis

Particle Size Analysis (PSA) determines the mass proportions of grains of different sizes, in accordance with current standards. The sample is washed on the \$80 \text{ } \mu\text{m}\$ sieve to separate the coarse fraction from the fine fraction. The former is characterized by sieving, while for the fine fraction, particle size analysis is performed by sedimentation. During sieving, the mesh sizes of the sieves are decreasing, ranging from 31,5 µm to 0,08 µm. The residue retained on each sieve is recorded in a table, which allows for the calculation of the percentage passing according to the following:

$$\%\, P = 100 - \%R_C \qquad \textbf{(2)}$$

Where $\%\, P$: is the percentage passing $\%R_C$: is the cumulative percentage retained (or refused)

This value allows the **particle size distribution curve** to be plotted on a semi-logarithmic paper. The sieve openings in mm are plotted on the abscissa (logarithmic scale), and the percentages passing are plotted on the ordinate (arithmetic scale).

2.3.3. Consistency Test: Determination of Atterberg Limits (AL)

Atterberg limits are water contents that cause soils to transition from one state to another. The transition from the solid state to the plastic state is referred to as the plastic limit, and the transition from the plastic state to the liquid state is referred to as the liquid limit. They are determined on fine soils. The determination of these water contents is done in two phases according to standard (NF P 94-051):

Determination of the Liquid Limit using the Casagrande Device

A fraction of the sample is taken and soaked in water for 24 hours. The sample is then washed through a 400 µm sieve to collect the passing fraction in a tare. This latter is dried in the oven at 105°C for 24 hours. The dry paste is then moistened to different water contents, kneaded, and spread into the cup using the Casagrande cup's spatula. The paste is separated into two parts using a grooving tool, then a series of regular blows are applied until the two edges of the groove meet over a length of approximately 1cm. Let N be the number of blows recorded, ranging between 15 and 35. The liquid limit is determined at N equal to 25 blows (N = 25).

Determination of the Plastic Limit

The soil is moistened to a certain water content. With this paste, the material is rolled on a glass table by hand into threads (or rolls) 3 mm in diameter and 10cm long. The water content that allows these dimensional characteristics to be achieved corresponds to the Plastic Limit (PL). The two previously determined criteria (Liquid Limit and Plastic Limit) allow for the calculation of the Plasticity Index (PI) according to Relation 3. This index is decisive in the selection of suitable materials for forming road subbase layers.

$$\boldsymbol{I_p = \omega_l - \omega_p} \quad \textbf{(3)}$$

I_p : Plasticity Index, ω_l : Liquid Limit, ω_p : Plastic Limit

2.4. Modified Proctor Test (NF P 94-093)

This test is performed according to standard NF P 94-093. Its purpose is to determine the water content (ω%) and the compaction effort at which a soil must be compacted to achieve a Maximum Dry Density (G_d). The material is moistened to several varied water contents and is compacted at a specific water content value, according to a well-defined process. For each water content value, the corresponding dry density is determined. Five (5) points are determined on the curve representing the dry density as a function of the water content. The Proctor curve is plotted, with the water contents on the abscissa and the dry densities on the ordinate. This bell-shaped curve allows for the determination of the Proctor optimum ω_{opt} which is the water content corresponding to the maximum density G_{dmax} obtained from the different experiments.

2.4.1. CBR and Penetration Test (NF P 94-078)

The purpose of this test is to determine the shear strength and swelling of a soil when it is submerged in water for four (4) days. Additionally, it is used to determine the compaction effort required for the sample to achieve an optimal density. This test consists of compacting three (3) samples at the Proctor optimum using different compaction energies (56, 25, and 14 blows) for each of the five layers, submerging them in water for four days, performing a penetration test, and recording the values. For the MESAGLA material, the sample is moistened to the Proctor optimum, then compacted in three (3) different molds of known mass and volume to apply different numbers of blows. According to the mold, 56, 25, and 14 blows are applied, respectively, layer by layer, across five layers placed in a mold. The filled mold is trimmed (or struck off) to remove the excess material, and the spacer discs (base support) are removed for weighing the assembly (mold + material) and then replaced after weighing. Finally, a filter paper is placed on each compacted material contained in the mold, along with a surcharge disk (or weight) of 2,27 kg. The three molds are submerged in a water tank for four days. For [Missing Material Name - likely MESAGLAS], the treatment and blowing process in the three molds is the same as that performed with MESAGLA, with the difference lying in the preparation of the samples for water immersion. Here, the sample is paraffined (or coated with wax) and left at ambient temperature for three days before being immersed in a water tank for four days. To perform the penetration test, the molds are placed on the CBR press, one after the other. The penetration piston (or plunger) is placed on the surcharge weights which help to center it. The piston moves at a rate of 1,27 mm /mn, and the dynamometer (or load cell) records the loads at the various penetrations. The different values of the piston's penetration into the material are displayed on the dial gauge (or comparator). The CBR index is calculated at 2,5 mm and 5 mm of penetration, with the higher value being retained.

3. **Results**

3.1. Particle Size Analysis

Figure 5 presents the particle size distribution curve of the MESAGLA samples.

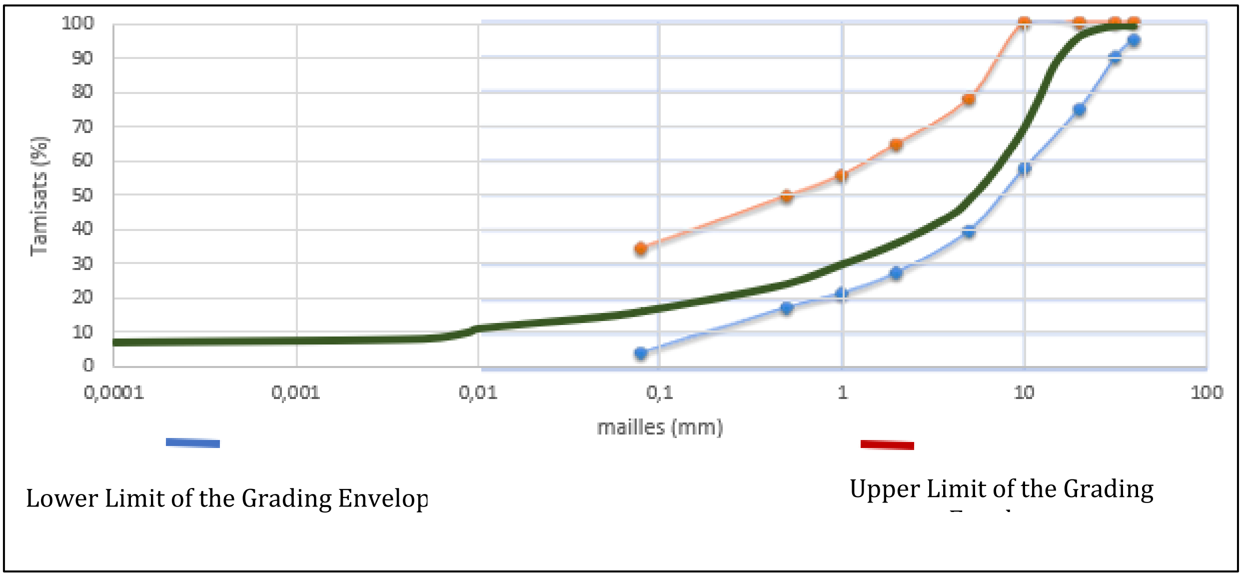

Figure 4 Particle Size Distribution Curve within the Typical Grading Envelope for a Lateritic Soil Usable as a Base Course Material (ISSIAKOU, 2016)

It is clear from this figure that the particle size distribution curve falls within the typical grading envelope for the base courses presented. Furthermore, the material, composed of the Unprocessed Sand Asphalt – Lateritic Gravel Mix, belongs to the 0/17 granular class. This means that 8 % of the sieved material has a size smaller than 0,5 mm and that 92 % corresponds to 17 mm. This indicates the presence of fines, sands, and small-sized gravel, forming a gravel-type aggregate. It could in this case be used in the structural layers (or pavement structure), primarily in the base course. Finally, it is composed of 18 % of fine particles (diameter less than 0,08 mm). This value is promising regarding the material's use in the road's structural layer, and particularly in the base course.

3.1.1. Atterberg Limits

The average Atterberg limits and plasticity index values are recorded in Table I.

Table 1 Atterberg Limits and Plasticity Index

$\boldsymbol{\omega_l}$ (%)	ω_p(%)	I_p(%)
39.2	20.32	18.88

The table reveals that the MESAGLA sample has a Plasticity Index of 18.88, which falls between 15 and 40. It therefore corresponds to the Plastic Soil. The relatively low Plasticity Index indicates that the material could be used in the road base course.

3.2. Results of the Modified Proctor Test

The results of the Modified Proctor test (water content and dry density) for the MESAGLA samples are presented in Figure [Insert Figure Number].

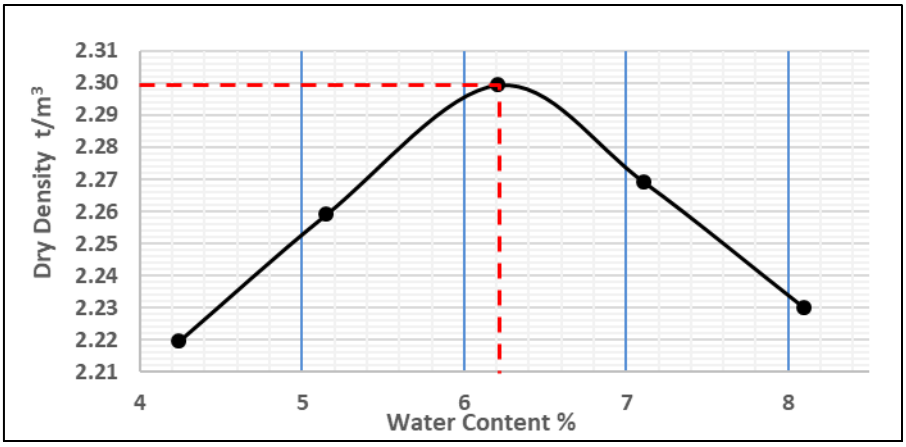

Figure 5 Modified Proctor Curve

The results of the Modified Proctor test show that the water content values increase with dry density up to a maximum before decreasing. Thus, the optimum water content of the samples is 6.21 % for a maximum dry density equal to 2,30 t/m^3. It is necessary now to verify whether the natural water content of the material is identical to the Proctor optimum. The result of this study is presented in table II.

Table 2 Détermination de la teneur en eau

Sample	**1**	**2**	**3**
Wet Mass (kg)	500	500	500
Dry Mass sec (kg)	471	471	471
Mass of Water (kg)	29	29	29
Water Content (%)	6.16	6.16	6.16

The water content of the material after its production is therefore equal to 6.16 %. Although it is lower than the value required by the project specifications, the water content of the MESAGLA samples is satisfactory for project execution. In fact, the difference could easily be offset by adding the missing quantity of water.

3.3. CBR and Penetration Test

The results of the CBR test for the MESAGLA samples are presented in the table below.

Table 3 CBR and Penetration Test

Number of Blows	**Water Content (%)**	**Wet Density**	**Dry Density**	**CBR Value**	**Compaction Ratio (%)**
56	6.21	2.42	2.3	59	99.15

The experiment resulted in good compaction but a CBR value that remains low for the construction of a base course. This could be remedied by undertaking material treatments. This might involve stabilization with a binder or the addition of crushed aggregate. This treatment would allow for the improvement of the mechanical properties of the said material.

4. Discussion

Our sample could be used in the construction of the base course. Indeed, according to the XP P 18-540 standard, aggregates with a maximum particle size equal to 20 (D = 20 mm) are adopted for base courses. Thus, the samples could substitute for untreated gravels (or untreated aggregates) of type GNT 3 and GNT4, which are of the 0/20 and 0/14 class respectively, and are usually designated for this use (KOFFI, 2021). Regarding the fine fraction content, it is acceptable. KOUASSI et al. (2020) note that in Côte d'Ivoire, the structural layer (or pavement foundation) is generally made from laterite that adheres to specific requirements, including a percentage of fines lower than 35\% to guarantee road quality. It seems necessary to stabilize the material using a binder if it is intended for use in the base course. Indeed, the fundamental criterion for a material's suitability for the base course is the CBR, which must be a minimum of 80 for a Compaction Ratio of 95 % at the Proctor optimum (SOULEY, 2016). ATTIMA et al. (2014) show that an addition of 5 % lime results in a significant increase in the CBR index of the clayey soils they worked with. Furthermore, the addition of crushed aggregate led to a relative increase in the CBR ranging from 2,5 % à 63 %, depending on the increase in the crushed rock content (MBENGUE, 2023). Thus, by considering treating the material, it could meet the requirements for its use in the base course. Regarding the plasticity index, FALL (1993) indicates that the maximum value for materials used in the construction of base courses is 25. The recycled material that is the subject of this work only has a plasticity index of 18.88.

5. Conclusion

Here is the summary of the study conducted on the sand asphalt–lateritic gravel mix, translated into native English:

The study conducted on the Sand Asphalt–Lateritic Gravel Mix (MESAGLAC) sourced from the Daloa–Issia road has demonstrated its potential as a substitute material for the road base course. The results obtained indicate the following:

- The material's particle size distribution complies with the specifications for road foundation layers.
- The plasticity index (PI = 18.88) meets the requirements for road construction.
- The maximum dry density (2,30 t/m^3) and the optimum water content (6,21 %) are favorable for proper implementation (compaction).

However, the CBR tests revealed a value below the criteria required for direct use in the base course. This result highlights the need for complementary treatment, either through cement or lime stabilization or by incorporating crushed aggregate.

Ultimately, the valorization (or reclamation) of this type of recycled material represents a sustainable and economically advantageous option, as it contributes to reducing quarry exploitation, limits environmental impact, and promotes the reuse of materials resulting from road decommissioning. Further studies focusing on the optimization of MESAGLAC treatment will confirm its suitability for widespread use in road projects in Côte d'Ivoire and elsewhere.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclsoed.

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