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Experimental study on the use of crushed granite sand for lithostabilization of lateritic soils in road construction

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Abstract

The use of local materials in road infrastructure provides a sustainable alternative to the high costs of conventional construction materials. However, certain lateritic gravels exhibit insufficient geotechnical properties for direct use in pavement layers. This study evaluated the potential improvement in the physical and mechanical properties of two types of lateritic gravels through the incorporation of crushed granite sand. Four addition rates were investigated: 15%, 20%, 25%, and 30%. The laboratory tests included particle size analysis, Atterberg limits, sand equivalent, Modified Proctor compaction, and California Bearing Ratio (CBR) tests. The results showed that the addition of crushed granite sand significantly enhanced the gradation and dry density of the materials while reducing their plasticity. For the first lateritic gravel, a 20% addition of crushed granite sand yielded a CBR value of 14 and a plasticity index (PI) of 15.8%, making it suitable for use as a subgrade layer, according to CEBTP standards. The second lateritic gravel, improved with 15% crushed sand, achieved a CBR of 35 and a PI of 19.7%, meeting the requirements for a foundation layer. These findings highlight the effectiveness of lithostabilization with crushed granite sand as a sustainable approach to improve and valorize local lateritic materials for road construction.

Keywords: Road Pavement; Lateritic Soil; Lithostabilization; Crushed Granite Sand; Physical-Mechanical Properties

1. Introduction

In tropical regions, such as Burkina Faso, lateritic materials are abundant and easily accessible natural resources for road construction. These materials result from the prolonged and intense weathering of parent rocks, leading to the formation of iron- and aluminum-rich horizons in the form of crusts or gravel [1]. Owing to their local availability and ease of extraction, lateritic gravels are commonly used in pavement layers, particularly in subbase and base courses. However, their use is conditioned by compliance with the strict geotechnical criteria defined by the Practical Pavement Design Guide for Tropical Countries (CEBTP) [2]. These requirements ensure the stability, durability, and bearing capacity of the road structures. According to CEBTP standards, only materials exhibiting appropriate Plasticity Index (PI) and California Bearing Ratio (CBR) values can be employed. However, the variable quality of lateritic deposits, combined with their intensive exploitation over time, has significantly reduced the availability of suitable materials. Consequently, contractors are often compelled to source materials from distant sites, substantially increasing construction costs.

To address this scarcity, several researchers have explored techniques to improve the geotechnical performance of lateritic gravels, including chemical stabilization using cement, lime, bituminous emulsions, or geopolymer binders [3–

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7]. Although effective, these methods are often limited by their high costs and dependence on imported additives. As a more economical and sustainable solution, lithostabilization has gained increasing attention. This approach aims to correct the particle size distribution and reinforce the granular skeleton, thereby enhancing the compactness and bearing capacity of the treated material without the need for chemical binders [8].

Numerous studies have confirmed the effectiveness of lithostabilization in lateritic soils. Research conducted in Cameroon, Senegal, Côte d'Ivoire, and Nigeria has shown that controlled additions of alluvial or dune sand can significantly reduce plasticity while increasing the maximum dry density and mechanical strength [9–12]. These findings highlight that the optimal sand proportion depends on both the nature of the lateritic soil and the characteristics of the sand.

In Burkina Faso, crushed granite sand derived from aggregate production plants remains underutilized, despite its promising geotechnical potential. Given its availability and favorable grain size characteristics, crushed granite sand represents a valuable alternative for the lithostabilization of lateritic materials used in road construction.

In this context, the present study aimed to evaluate the effect of crushed granite sand addition on the physical and mechanical properties of two types of local lateritic gravels that initially do not meet CEBTP standards. The objective of this study was to identify the optimal sand proportions that can enhance these materials for use in road pavement layers, particularly in subgrade and subbase courses.

2. Materials and methods

2.1. Materials used

The study was conducted using two types of lateritic gravels collected from the eastern region of Burkina Faso. Samples were collected from two borrow pits located in the Gourma Province, specifically in the vicinity of Fada N'Gourma. After sampling, the materials were stored in sealed bags and transported to the laboratory for geotechnical characterization.

The sand used in the experimental formulations was crushed granite sand (CGS) with a grain size range of 0/5 mm. It was obtained by crushing a granitic rock extracted from a quarry located approximately 20 km from the city of Ouagadougou, Burkina Faso. This crushed granite sand was selected for its angular particle shape and clean texture, which are expected to improve the mechanical interlock and compaction of lateritic mixtures.

2.2. Mix design

The mix design stage involved incorporating crushed granite sand (CGS) into the lateritic gravels at different mass percentages to assess its influence on the physical and mechanical properties of the resulting materials. The selected incorporation rates were 15%, 20%, 25%, and 30%, based on previous research findings and preliminary tests conducted to identify the range of optimal geotechnical performance. Prior to mixing, the constituent materials were air-dried and sieved through a 20 mm mesh to remove oversized particles and ensure a homogeneous particle size distribution (PSD). Each formulation was prepared by dry mixing to ensure a uniform distribution of crushed granite sand within the lateritic matrix.

2.3. Experimental methods

The prepared samples were subjected to a series of standardized geotechnical tests to determine their physical and mechanical properties.

- A dry sieve analysis was performed on the different materials to examine the impact of sand addition on the grain size distribution of the lateritic gravels [13];
- Atterberg Limits (NF EN 17892-12) [14]: The tests were performed on the fine fraction (< 425 µm) of each mixture to evaluate the evolution of plasticity as a function of the crushed granite sand content.
- The Modified Proctor Test (NF P 94-093) [15] was conducted to determine the optimum water content (OWC) and maximum dry density (MDD) of each mixture. These parameters are essential for defining the laboratory compaction conditions and reproducing field compaction practices as closely as possible.
- California Bearing Ratio (CBR) Test (NF P 94-078) [16]: CBR tests were performed on specimens compacted to 95% of the maximum dry density obtained from the Modified Proctor test. CBR was evaluated after four days of immersion in water. This test assesses the load-bearing capacity and penetration resistance of a material, which are key indicators of pavement layer classification.

All tests were conducted under controlled laboratory conditions, maintaining an average temperature of 25 ± 2 °C and constant relative humidity to ensure the reproducibility and reliability of the results. For each formulation, the tests were repeated three times, and the mean values were used for comparative analysis.

The overall objective of this experimental approach was to identify the optimal crushed granite sand incorporation rate that enhances the compaction and bearing capacity of lateritic gravels while reducing their plasticity, thereby meeting the standard requirements for road construction.

2.4. Reference standards

The interpretation of the experimental results was based on the requirements of the Practical Pavement Design Guide for Tropical Countries developed by CEBTP [2], which remains a widely used reference for road construction projects at the national level. This guideline specifies the quality criteria required for materials used in various pavement layers, particularly the subgrade, subbase, and base courses.

For subgrade layers, the recommended criteria include a plasticity index (PI) lower than 25% and a California Bearing Ratio (CBR) greater than or equal to 10% at 95% of the Modified Proctor Maximum Dry Density (MDD).

For subbase layers, materials must exhibit a PI below 30 %, a CBR on average of 30% at 95% MDD, and a minimum dry density of 1.8 t/m^3.

Finally, for base layers, more stringent specifications apply: a PI below 15%, a CBR on average of 80% at 95% MDD, and a minimum dry density of 2.0 t/m^3.

These reference values were used to assess the suitability of lateritic and crushed granite sand mixtures for use in different pavement layers. Thus, a material meeting the subgrade specifications may be used for embankments or lower pavement layers, whereas a material fulfilling the subbase or base layer requirements can serve as a structural layer, ensuring improved bearing capacity and enhanced pavement durability.

3. Results and discussion

3.1. Characteristics of materials

Particle size analysis of the two lateritic gravels, GL1 and GL2, revealed a grain size distribution generally suitable for road construction applications. The gradation curves presented in Figure 1 indicate that both materials fall within the CEBTP-recommended envelope for subbase layers, demonstrating a well-graded particle distribution with a balanced proportion of coarse and fine fractions. However, when compared with the CEBTP specification range for base layers (Figure 2), only GL1 remained entirely within the prescribed limits. GL2 exhibited a slight deviation, with its fine fraction exceeding the upper boundary of the recommended gradation envelope.

The measured fines contents were 17% for GL1 and 22% for GL2. These values are below the maximum limit of 35% specified by the CEBTP for materials intended for subgrade or subbase layers, confirming that both gradations are acceptable for such applications. Nevertheless, for base layers, where the allowable fine content must remain below 20%, only GL1 met the requirement. The higher fines content in GL2 may adversely affect the mechanical stability and compaction behavior of the material when used in high-stress structural layers.

The results of the Modified Proctor test revealed MDD of 2.035 t/m^3 for GL1 and 2.12 t/m^3 for GL2, both obtained at an OWC of 10%. These values exceed the minimum thresholds recommended by CEBTP: 1.8 t/m^3 for subbase layers and 2.0 t/m^3 for base layers. That indicate that both materials exhibit satisfactory compactability under standard compaction energy requirements.

The Atterberg limits yielded plasticity index (PI) values of 16.5% for GL1 and 23% for GL2, respectively. These results comply with the CEBTP specifications for subgrade (PI < 25%) and subbase (PI < 30%) applications but remain above the limit required for base layers (PI < 15%). Hence, both materials exhibit moderate to high plasticity, which could limit their performance in the upper structural layers of pavement systems.

The California Bearing Ratio (CBR) tests, conducted at 95% of the Modified Proctor maximum dry density, produced values of 5% for GL1 and 23% for GL2. These bearing indices are below the CEBTP minimum requirements for all pavement layers, namely, 10% for subgrade, 30% for subbase, and 80% for base layers.

Overall, these results indicate that GL1 lacks the mechanical performance required for use in pavement layers. GL2, although exhibiting moderate plasticity and a fines content slightly above the base layer standard, may still be suitable for subgrade applications, provided that its mechanical properties are improved. Therefore, these findings highlight the need to enhance the performance of both materials through lithostabilization, particularly by incorporating granular additives such as crushed sand, to increase their bearing capacity and suitability for use in subbase or base courses.

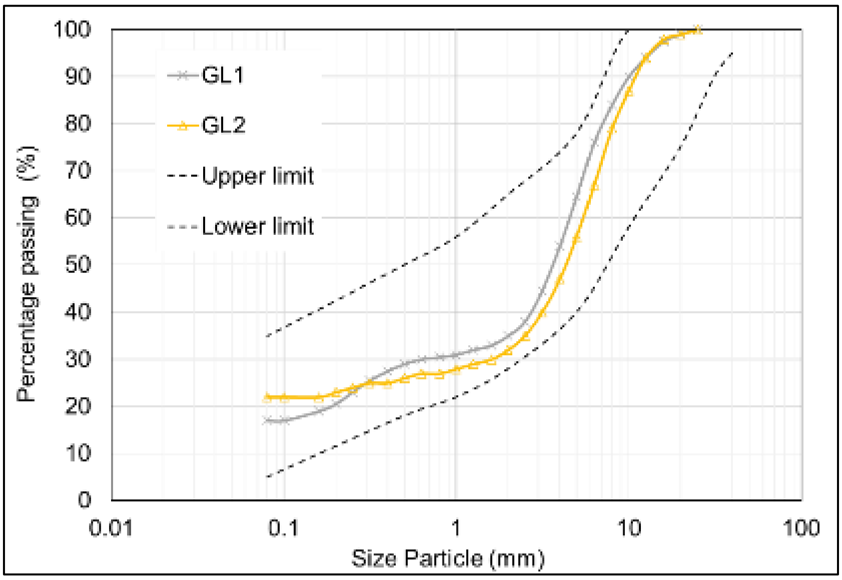


Figure 1 Grain size distribution of GL1 and GL2 compared with CEBTP for application in subbase layer

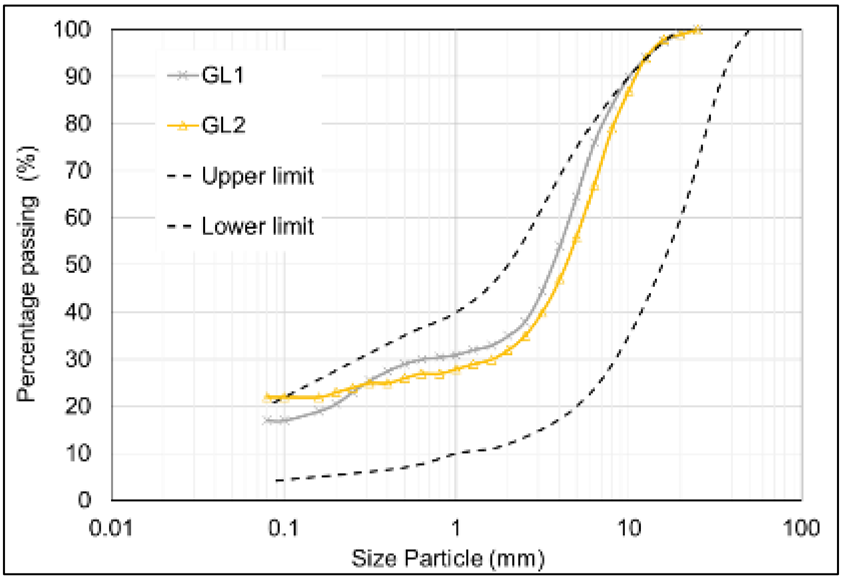


Figure 2 Grain size distribution of GL1 and GL2 compared with CEBTP for application in base layer

The grain size distribution of the crushed granite sand is shown in Figure 3. It's a well graded and very clean sand. It has a density of 2640 kg/m^3, a bulk density of 1620 kg/m^3 and a Fineness modulus of around 3.

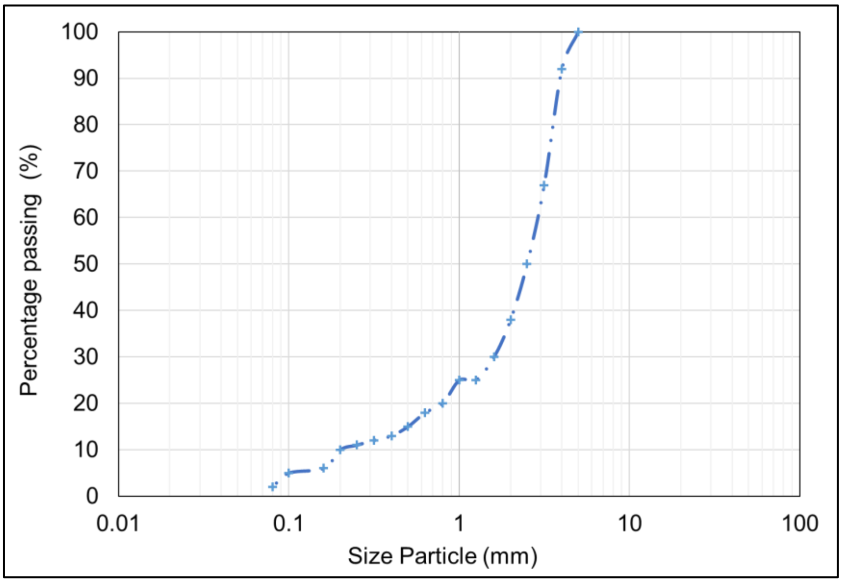
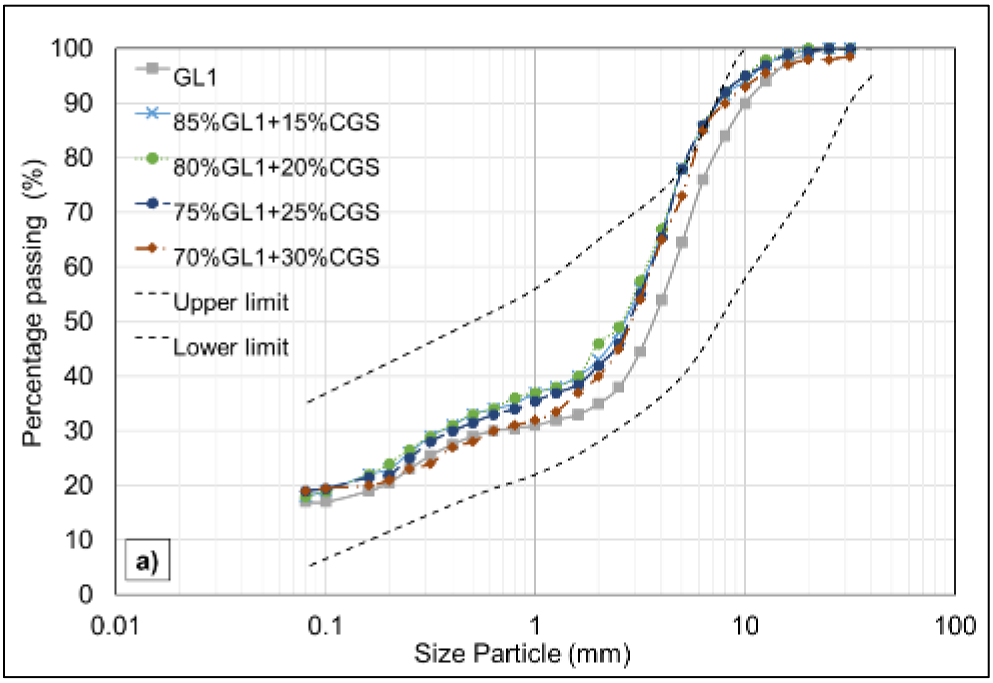


Figure 3 Grain size distribution of crushed granite sand

3.2. Effect of crushed granite sand on Particle Size Distribution

The addition of crushed granite sand significantly improved the particle size continuity of the lateritic materials. The gradation curves of the blended mixtures progressively entered the CEBTP-recommended envelopes starting from 20% sand addition for GL1 and as early as 15% for GL2, indicating a marked improvement in the grain size distribution. This adjustment resulted from the well-balanced proportions of fine and coarse particles in the 0/5 mm crushed sand, which filled the intergranular voids and enhanced the particle packing density.

For GL1, the gradation curves corresponding to mixtures containing 15%, 20%, 25%, and 30% crushed granite sand fell entirely within the CEBTP specification range for subbase layers (Figure 4.a). This reflects a clear improvement in the grading uniformity and skeleton continuity. However, for the base layer requirements, the curves remained partially above the upper boundary of the recommended envelope because of the additional fine fraction introduced by the crushed sand (Figure 4.b).



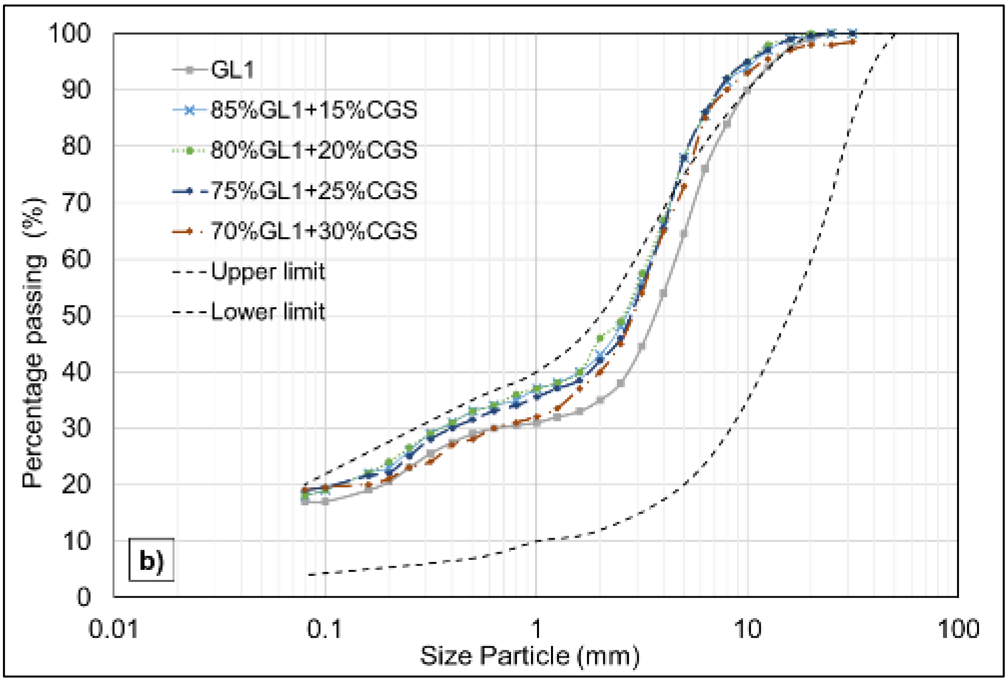
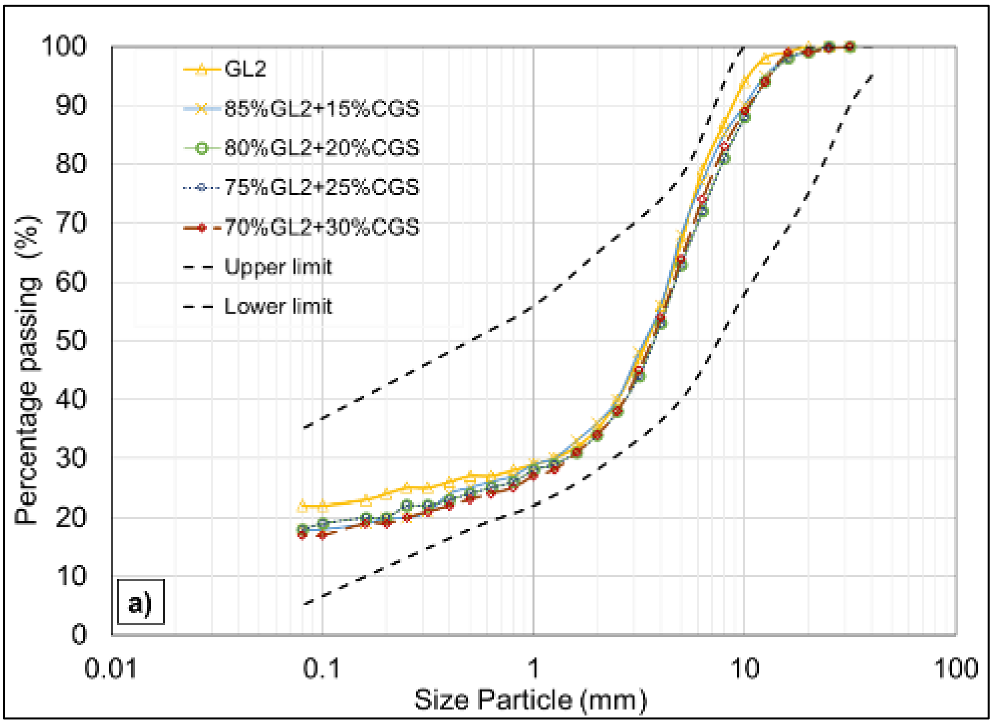


Figure 4 Grain size distribution of GL1 a)before and b) after addition of crushed granite sand for application in subbase layer

For GL2, the gradation curves corresponding to the four incorporation rates exhibited a trend similar to that observed for GL1 (Figure 5 a) and b)). They fit well within the CEBTP envelope for the subbase layers but remained slightly above the upper boundary for base layer specifications.



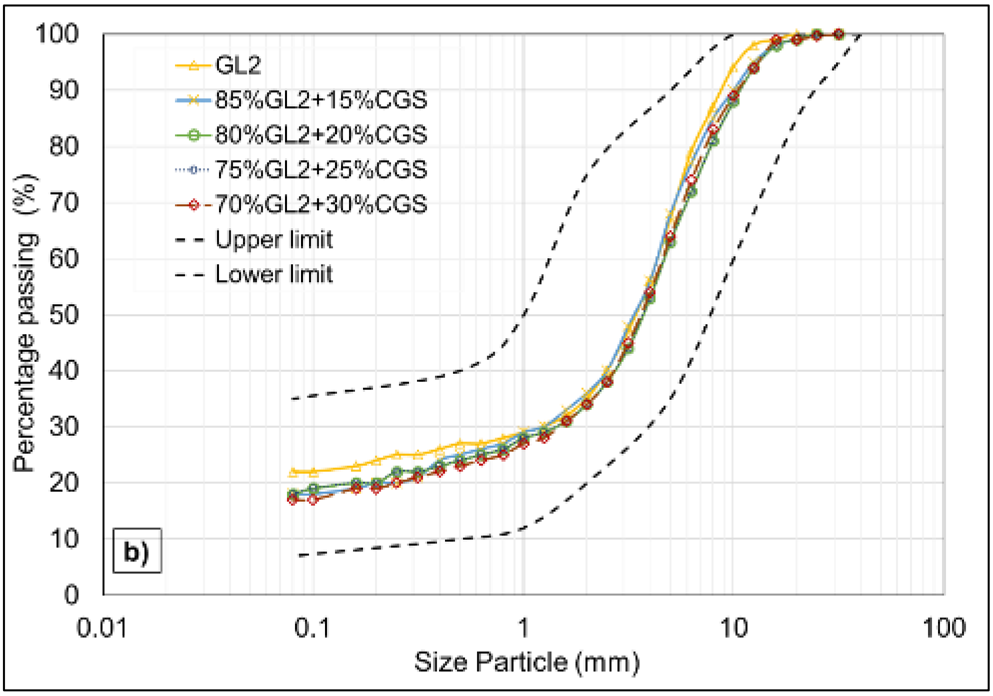


Figure 5 Grain size distribution of GL1 a)before and b) after addition of crushed granite sand for application in base layer

This behavior indicates a slightly unbalanced distribution between the fine and coarse fractions, although the overall grading and texture of the mixture were considerably improved compared to the natural lateritic material.

These results show that the inclusion of crushed granite sand refines the particle size distribution and fills the intergranular voids, leading to a more continuous and well-graded curve. This improvement promoted a higher compaction efficiency and resulted in an increased dry density. The angular and rough surface texture of the crushed granite sand particles also enhances the interlocking between grains, thereby improving the mechanical cohesion of the mixture.

However, the addition of crushed granite sand was accompanied by an increase in the fine fraction, ranging from 1% to 6% depending on the incorporation rate. This variation remains within the CEBTP limits for subbase applications but may restrict the use of the mixture in base layers when the fine content exceeds approximately 12%.

Similar observations were reported by Savadogo et al. [17], who found that incorporating 30% dune sand improved the suitability of lateritic soils for use as subbase layers. Almeida et al. [18] reported comparable results with fine sand addition.

In summary, lithostabilization using crushed granite sand acts as an effective granulometric corrector, enhancing the material structure and complying with the CEBTP specifications for subbase layers. Nonetheless, its effectiveness remains limited for base courses, where a lower fine content is required to achieve optimal performance.

3.3. Evolution of the physical properties

3.3.1. Effect of crushed granite sand on the plasticity of the mixtures

Atterberg limit tests were conducted to assess the influence of crushed granite sand addition on the plasticity of the studied lateritic gravels. According to the CEBTP specifications, the plasticity index (PI) must be lower than 30% for subgrade and subbase layers and below 15% for base layers.

For GL1, the variation in the plasticity index showed a clear decreasing trend with increasing crushed granite sand content: 16.5% for the natural material, and 16.0%, 15.8%, 15.0%, and 14.6% for 15%, 20%, 25%, and 30% sand addition, respectively (Table 1). This progressive reduction in the PI reflects a noticeable improvement in the material texture. This decrease can be attributed to the partial substitution of fine clayey particles with coarser non-plastic grains from the crushed sand. Similar findings were reported by Savadogo et al. [17], who observed a comparable decrease in plasticity index when stabilizing lateritic soils with dune sand. This effect is commonly associated with the dilution of the clay fraction and the reduction of interparticle cohesion, as noted by Ndiaye et al. and Mbengue et al. [11,19] in their studies on the lithostabilization of West African lateritic soils.

Table 1 Physical properties of mixtures

	GL1				GL2			
%CGS	LL (%)	PI (%)	OWC (t/m^3)	MDD (t/m^3)	LL (%)	PI (%)	OWC (t/m^3)	MDD (t/m^3)
0	39.1	16.5	10.0	2.035	52.0	23.0	10	2.12
15	40.9	16.0	9.5	2.070	46.9	19.7	9.1	2.12
20	42.1	15.8	9.6	2.070	45.8	19.4	9.2	2.12
25	42.3	15.0	9.5	2.080	45.1	19.0	8.2	2.14
30	42.1	14.6	10.0	2.085	43.9	18.8	8.8	2.15

%G: content of crushed granite sand (%); LL: Liquid Limit; PI: Plastic Index; OWC: Optimum Water Content; MDD: Maximum Dry Density

Similarly, GL2 exhibited a measurable reduction in plasticity with increasing crushed granite sand content: the plasticity index decreased from 23% (natural state) to 19.7%, 19.4%, 19.0%, and 18.8% for incorporation rates of 15%, 20%, 25%, and 30%, respectively. This trend indicates a clear improvement in the plastic behavior of the material, although the final PI values remained slightly above the limit required for base layer applications.

The overall results demonstrate that lithostabilization using crushed granite sand effectively reduces the plasticity of lateritic gravels, particularly for materials rich in clay. In comparison with CEBTP standards, both improved materials, GL1 and GL2, comply with the requirements for subgrade and subbase layers (PI < 30%). However, only the mixture of GL1 + 30% crushed granite sand (0/5 mm) met the stricter criterion for base layers (PI < 15%).

These findings confirm the beneficial role of crushed granite sand in lowering soil plasticity, while emphasizing the importance of determining an optimal sand incorporation rate suited to the specific characteristics of each lateritic material.

3.3.2. Effect on Maximum Dry Density and Optimum Water Content

The results of the Modified Proctor test revealed a progressive improvement in the MDD and a slight decrease in the OWC as the proportion of crushed granite sand increased.

For GL1, the MDD increased from 2.035 to approximately 2.120 t/m^3 with 30% crushed sand, whereas the OWC remained close to 10%. This increase in density indicates better compaction of the material, resulting from a corrected particle size distribution and filling of intergranular voids by the angular particles of crushed sand. A similar trend was observed for GL2, where the MDD also exceeded 2.1 t/m^3.

This evolution confirms that the crushed granite sand acts as a texture-correcting material, promoting particle rearrangement and reducing voids within the matrix. However, its effect on the OWC remains limited. The minor variation observed can be attributed to the mineralogical composition of the lateritic material, which is still rich in fine absorbent particles (clays and iron oxides) that maintain a relatively stable adsorption capacity.

These findings are consistent with those reported by Savadogo et al. [17], who highlighted that such improvement is more pronounced when the sand used is angular and well-graded, as observed in the present study.

3.4. Mechanical behavior

The California Bearing Ratio (CBR) is a key parameter for assessing the load-bearing capacity and mechanical quality of pavement materials. According to the CEBTP [2] specifications, a material can be used in the subgrade layer if CBR ≥ 10%, in the subbase layer if CBR ≥ 30%, and in the base layer if CBR ≥ 80% at 95% of MDD.

For GL1, the experimental results showed a marked increase in the CBR after immersion with progressive additions of crushed sand. The CBR values increased from 5% in the material natural state to 10%, 14%, 16%, and 16% for incorporation rates of 15%, 20%, 25%, and 30%, respectively (Figure 6). This evolution indicates a significant improvement in the bearing capacity up to a threshold of approximately 25%, beyond which the gains become marginal. This improvement can be attributed to the filling of intergranular voids and particle rearrangement induced by the crushed sand, leading to higher compaction and better penetration resistance. Similar trends were reported by Savadogo et al. [17], who observed that partially replacing the fine fraction of Kamboinsin laterites with angular dune sand enhanced the maximum dry density and reduced water sensitivity, resulting in a more stable bearing capacity after immersion.

Likewise, GL2 exhibited higher initial CBR values, reflecting a naturally denser structure (Figure 6). The addition of crushed granite sand further enhanced this performance, with values increasing from 23% (0% SC) to 35%, 35%, 35%, and 39% for incorporation rates of 15%, 20%, 25%, and 30%, respectively. The effect tended to stabilize beyond 20% crushed sand, suggesting that the material reached an almost optimal granular structure.

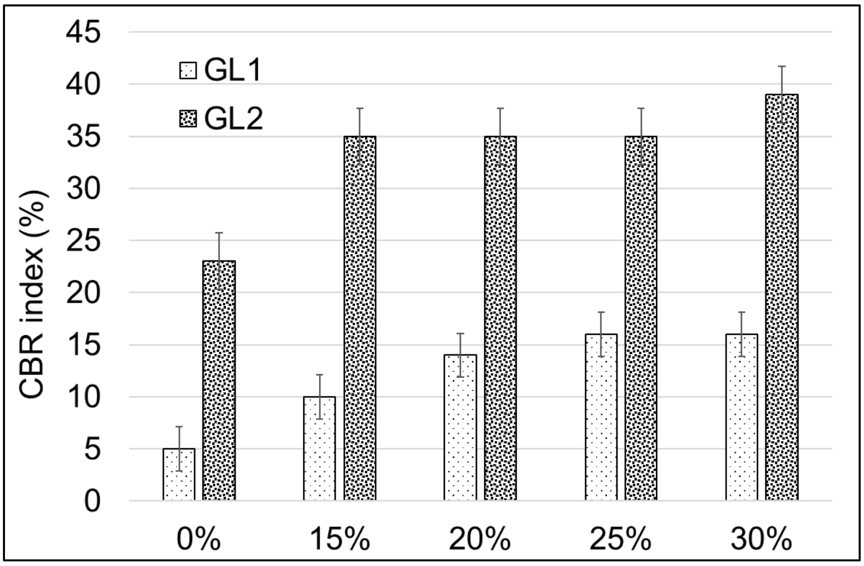


Figure 6 CBR index of lateritic materials compacted to 95% of MDD before and after addition of crushed granite sand

Overall, lithostabilization with crushed granite sand is an effective method for improving the bearing capacity of lateritic gravels. However, this effect remains limited to an optimal proportion range, beyond which additional sand does not yield further benefits. These findings align with the literature, which generally identifies the 15–25% range as optimal for maximizing the density and strength without compromising the material cohesion. According to Seklokla et al. [20], lithostabilization with 0/5 crushed granite sand is suitable for use in subbase layers, but an additional hydraulic binder is required for base layer applications. Conversely, Almeida et al.[18] reported that sand addition did not significantly improve the mechanical performance of lateritic soils, although it enhanced their adaptability to repeated load conditions.

4. Conclusion

A study on the lithostabilization of lateritic gravels using crushed granite sand highlights the potential of this local material as a geotechnical improvement agent for pavement structures. The results of the granulometric, physical, and geotechnical tests confirmed that the progressive incorporation of crushed granite sand significantly enhanced the quality of the studied materials.

From a granulometric standpoint, the addition of crushed granite sand improved the particle distribution and allowed the grading curves to fit partially or fully within the CEBTP recommended limits. This adjustment indicates a higher potential for compaction, which is consistent with other studies that have reported a positive effect of sand addition on the granulometric continuity of lateritic soils.

Regarding the physical properties, the gradual decrease in the plasticity index (PI) with increasing sand content demonstrated a notable reduction in the material plasticity. For GL1, the PI decreased from 16.5% to 14.6% for incorporation rates up to 30%, meeting the CEBTP requirements for base layers, whereas GL2 remained suitable for subbase applications.

The geotechnical properties, particularly the bearing capacity (CBR index), exhibited a similar trend: the CBR values increased with higher proportions of crushed granite sand and stabilized beyond 25% crushed granite sand. For GL1, the CBR rose from 5% to 16% at 95% of MDD, while for GL2, it reached 39% with 30% crushed granite sand. These results reflect a substantial improvement in the bearing capacity, which is attributed to the void filling and granular skeleton densification effects.

According to the CEBTP standards, GL1 mixtures containing 20–30% crushed granite sand are suitable for subgrade and subbase layers, whereas GL2 mixtures are limited to subbase use.

Overall, lithostabilization with crushed granite sand appears to be a local, sustainable, and cost-effective alternative to imported materials for road construction in the tropics. It promotes the valorization of local resources and contributes to infrastructure durability.

For future research, it would be relevant to further investigate the hydric and mechanical long-term behavior of these mixtures under simulated traffic loading, as well as their environmental durability across different pedoclimatic conditions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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