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Influence of Some Plant Fibers on the Mechanical Performance of Composite Materials

Serge Pierre Quenum[1], Yvette S. Tankpinou Kiki[1], Judicaël Koffi Agbelele[2], Crespin Prudence Yabi[3], Edmond Codjo Adjovi[3]

[1]Laboratoire de Procédés et d'Innovation Technologique, UNSTIM, Abomey, Benin
[2]Laboratoire Pluridisciplinaire de l'Enseignement Technique, UNSTIM, Abomey, Benin
[3]Laboratoire d'Etudes et d'Essais en Génie-Civil, UNSTIM, Abomey, Benin
Email: yvettestankpinou@gmail.fr

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Abstract

This work focused on the search for biobased materials capable of being used in road techniques as soil inclusions, and on studying the influence of their incorporation on the characteristic parameters of pavement layers. To this end, pineapple, cyperus and imperata plant fibers, due to their endemic availability, were used as reinforcement on sourced materials, notably bar soil, lateritic gravel and silty sand. Complete identification and mechanical tests (Proctor and CBR) were carried out on materials in their natural state (soil) and on composite materials (soil + plant fibers) in the laboratory to determine their classification in road geotechnics, their compaction parameters and their mechanical behavior. Firstly, the various types of 2.5 cm long fibers were incorporated into the different types of soil at mass contents of 1% and 2%. This part of the study showed that the pineapple fiber composite incorporated into class A2 bar soil offered the best results, with a 38% gain in CBR index compared with the natural soil. Pineapple fibers incorporated at 1% in lateritic gravel raise the CBR value of the reinforced soil to 10% of the CBR value of the natural soil and to 7% for silty sand.

Keywords

Plant Fibers, Soils, Composite Materials, Reinforcement

1. Introduction

The issue of sustainable development deserves careful consideration in all human endeavors. Environmental concern is, in fact, becoming increasingly growing in the face of the damage caused to nature by engineering and industrialization, including the construction of infrastructure. This awareness, supported by new environmental regulations increasingly strict, requires the development of new ecological materials to meet the challenge of sustainable development [1]. This awakening aims for technical, environmental and economic performance, through a mix of solutions. For large road construction projects, the use of large quantities of quality materials is necessary to meet the ever-increasing traffic demands [2]. The use of natural fibers in the manufacture of composites attracts great interest from researchers due to their biodegradability and acceptable mechanical strength [3] [4]. Also, the south of Benin has several types of fibers which constitute agricultural waste [5]. Recycling this waste while contributing to the preservation of the environment would reduce the need for quality materials. Some of these plant fibers have specific mechanical properties which make them potential reinforcing elements in construction materials [6] [7]. Thus, the use of natural plant fibers as reinforcement in road materials instead of geosynthetics or glass or carbon fibers appears to be a good alternative. These biofibers have several advantages for use, low density, low production cost, non-abrasive nature, high filling level, low energy consumption and low environmental impact [8] [9]. It is in this context that this research article, which reports on the development of new materials for eco-construction through the study of the physical and mechanical characteristics of soils reinforced with plant fibers for use in road geotechnics is set.

2. Study Environment, Materials and Methods

Local materials available from the Atlantic department located in the south of Benin were used follows **Figure 1**.

Three categories of soil were selected: silty-clay sand of the bar soil type (**Figure 2**), lateritic gravel (**Figure 3**), silty sand (**Figure 4**) and on the other hand three fibers selected, because of their availability and accessibility: the fibers of pineapple leaves (**Figure 5**), cyperus articulatus (**Figure 6**) and imperata cylindrica (**Figure 7**).

After drying at room temperature, the dehydrated plant materials are cut into 2.5 cm pieces, drawing inspiration from the studies of Maity *et al.* (2011) who, in their study on two types of sand mixed with jute and coconut fibers, found a substantial increase in CBR for the case of fine sand reinforced with fibers of 0.5 cm in length [10] and F. Omrani *et al.* In their work on Analysis and control of the variability of the properties of natural fibers at the fiber, yarn and reinforcement scale [11].

The physical and mechanical characteristics of the soils in their natural state were determined using the following tests: particle size analysis by sieving (NF EN ISO 17892-4), the Atterberg limits (NF EN ISO 17892-12), the modified Proctor test (NF P 94-093), the CBR test (NF P 94-078) Then, in order to assess the geotechnical performances acquired by the soil materials following the reinforcement, plant fibers 2.5 cm long were incorporated at a mass percentage of 1% and 2%. Eighteen (18) composite materials were made as follows in **Table 1**.

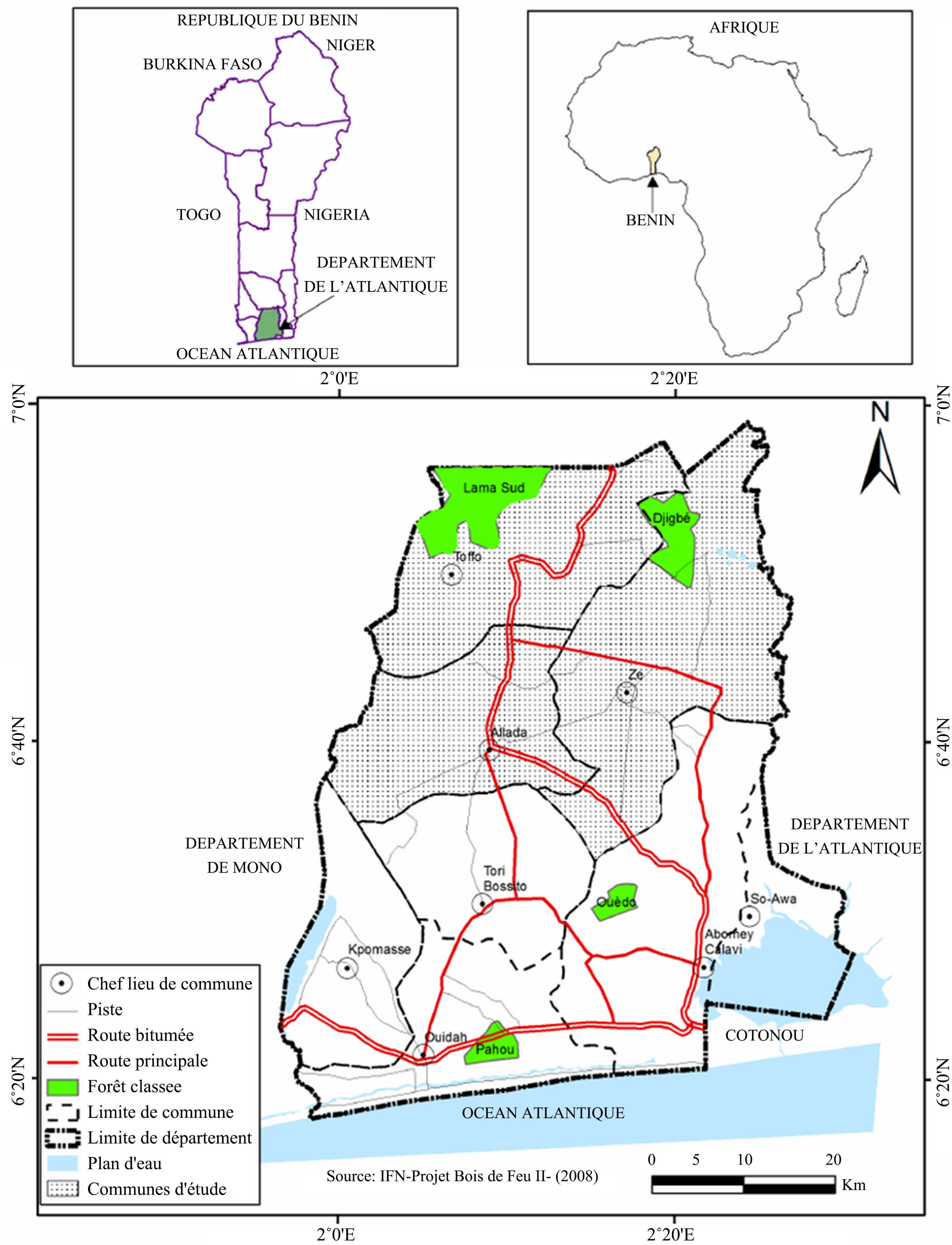


Figure 1. Geographic location of the study environment.

Figure 2. Dried bar soil.

Figure 3. Dried lateritic.

Figure 4. Dried silty sand.

Figure 5. Pineapple leaves.

Figure 6. *Cyperus articulatus*.

Figure 7. *Imperata cylindrica*.

Table 1. Summary table of the different study composite materials.

Ground	Composite materials	Fiber percentage	
		1%	2%
Bar land	Earthen bar + Pineapple	TBA 1%	TBA 2%
	Bar earth + Cyperus	TBC 1%	TBC 2%
	Bar Earth + Imperata	BIT 1%	BIT 2%
Grave lateritic	Gravel lateritic + Pineapple	GLA 1%	GLA 2%
	Gravel lateritic + Cyperus	GLC 1%	GLC 2%
	Grave lateritic + Imperata	GLI 1%	GLI 2%
Silty sand	Silt sand + Pineapple	SSA 1%	SSA 2%
	Silty sand + Cyperus	SSC 1%	SSC 2%
	Silty sand + Imperata	SSI 1%	SSI 2%

These new materials were then subjected to the modified Proctor (NF P 94-093) and CBR (NF P 94-078) tests.

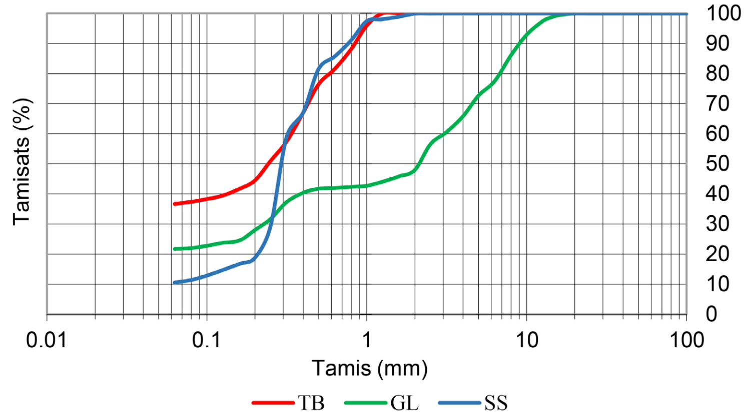
3. Results

3.1. Results of Tests on Soils in Their Natural State

The particle size curves of the soils are presented as follows in Graph 1.

The test results are summarized in the Table 2. The GTR soil classification was used to assess the soils studied [12].

It appears that the bar soil is class A2, therefore a clayey soil, the lateritic gravel is class B5, therefore a clayey gravel, and the silty sand is class B1. Also, lateritic gravel and bar earth have higher optimal water contents than silty sand, this could be explained by the rate of fine particles in these soils compared to silty sand which is a sandy soil and therefore less insensitive at the water. Of the three soil types, silty sand has the best CBR, followed by lateritic gravel and barren soil.



Graph 1. Grain size curves of the soils studied.

Table 2. Summary of natural soil test results.

	Bar land (TB)	Grave lateritic (GL)	Silty sand (SS)
% increasing to 2 mm	100	47.97	99.94
% increasing to 0.08 mm	37.40	21.99	11.43
Liquidity limit	42	28	27
Plasticity index	18	11	8
Methylene Blue value test	0.40	0.32	0.11
Dry density in t/m^3	1.98	2.17	1.94
Proctor Optimum in %	10.5	9.9	8.5
CBR index in %	21	48	56

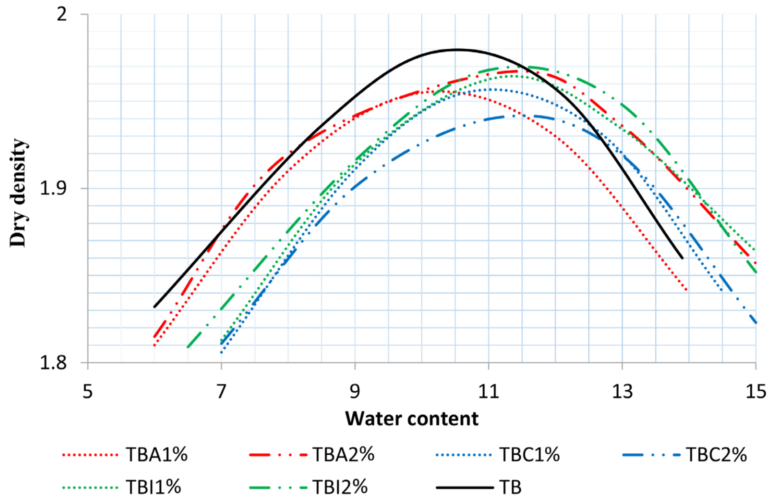
3.2. Composite Material Testing Results

The Proctor curves obtained on composite materials are presented in the following graphs for each composite material according to the type of soil initially, then according to the type of fiber (Graphs 2-4).

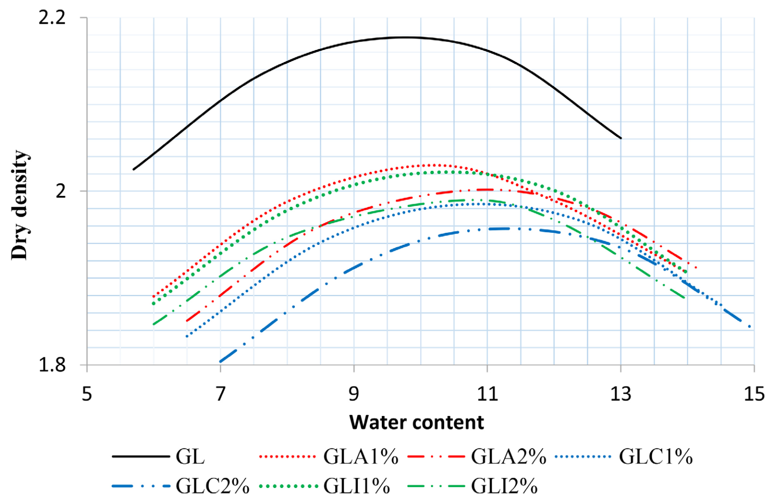
The Proctor curves for each type of soil as a function of plant fibers were highlighted in order to study the influence of the nature of these soils on the Proctor references when each fiber is incorporated (Graphs 5-7).

4. Analysis and Discussion

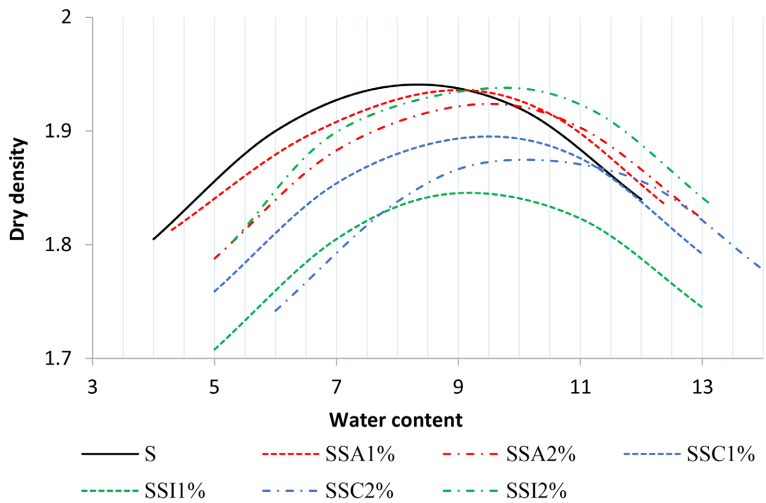
Examination of the curves allows us to note, for each of the fibers incorporated in the soils at different percentages (1% and 2%), an increase in the optimal water content and a reduction in the maximum dry density compared to the soils at natural state. In general, it is noted that the water content does not undergo a large variation for lateritic gravel and silty sand but with bar earth after incorporation of fibers at 1% and 2%. The parameter that varies the most when incorporating fibers into soils is the maximum dry density and this also varies depending



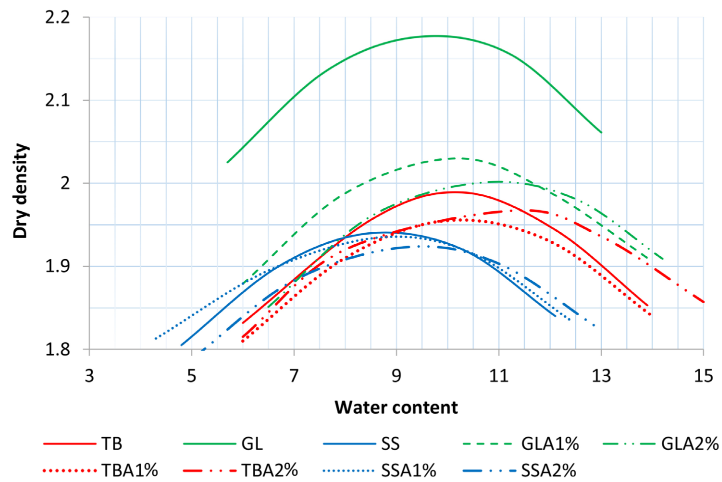
Graph 2. Proctor curves of bar soil with 1% and 2% plant fibers.



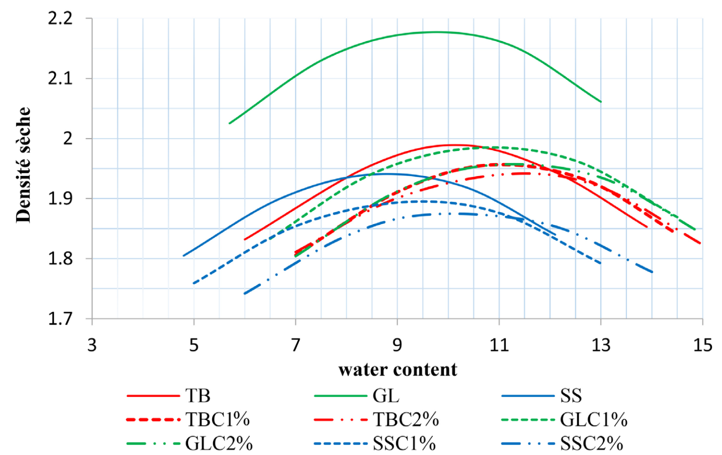
Graph 3. Proctor curves of lateritic gravel with 1% and 2% plant fibers.



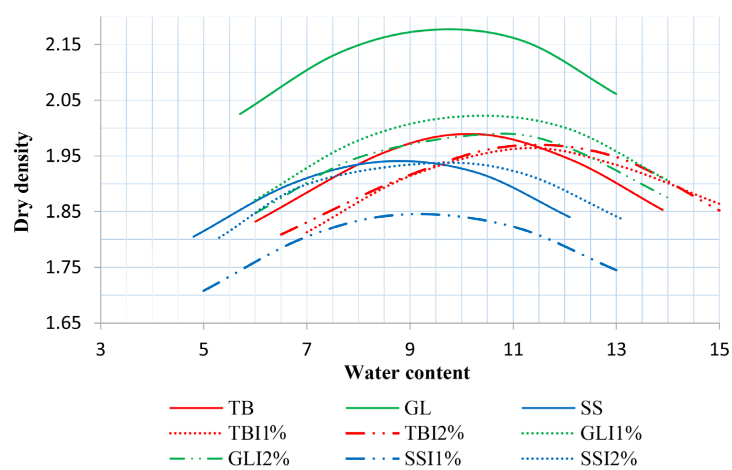
Graph 4. Proctor curves of silty sand with 1% and 2% plant fibers.



Graph 5. Influence of the nature of the soil on the proctor references of pineapple-reinforced soils.



Graph 6. Influence of the nature of the soil on the proctor references of soils reinforced with cyperus.



Graph 7. Influence of the nature of the soil on the proctor references of soils reinforced with imperata.

on the type of soil and the fiber used. This same observation was made by Marandi *et al.* [13] who noticed a decrease in maximum dry density and an increase in optimal water content with the addition of palm fibers in the matrix of a silty sand (SL). Similarly Santhi *et al.* [14] found from compaction tests at optimum Proctor normal (OPN), on a very plastic clay (At) mixed with sisal fibers that the maximum dry density decreases when the length and fiber content increases.

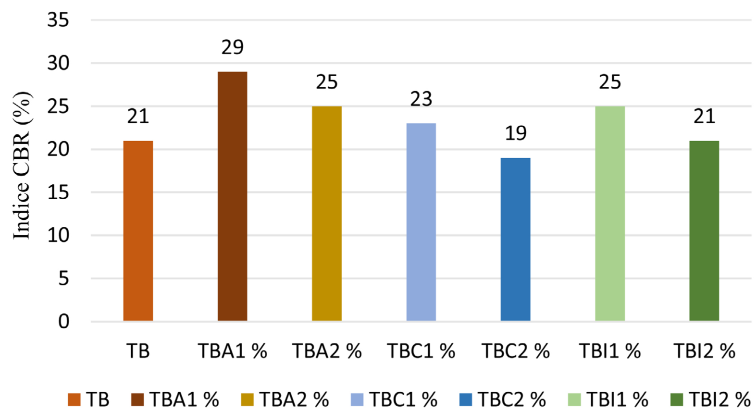
The CBR results obtained for each composite material depending on the type of soil and the different fibers used at incorporation rates of 1% and 2% are presented according to the types of composite soil.

- **Bar soil**

We notice that after the incorporation of fibers into the matrix at different contents, the CBR index of the composites increases for a fiber content of 1% and decreases for a content of 2% compared to the CBR of the soil in its natural state (**Graph 8**). At 1% content, pineapple fibers offer a gain of up to 38% in the bearing capacity of reinforced soil. Cyperus fibers, a gain of 9.5%, or four times less than the gain obtained for pineapple fiber. With imperata fibers, we obtain a gain of 19%, or half of the gain offered by pineapple fibers. At 2% content, the cyperus and imperata fibers incorporated into this soil do not offer a consistent gain in resistance. Only pineapple fiber maintains the gain at 19%. Thus, among the three fibers incorporated into this soil, pineapple fiber offers a better gain in strength compared to other fibers when it is incorporated into the matrix at a content of 1% and 2% at a length of 2.5 cm. Babu, GL *et al.* [15], by studying the effect of fiber inclusions on the strength and stiffness behaviors of the soil explained the role of fibers as a reinforcing element. The same observations were made with R. Ramkrishnan *et al.* [16] in their study based on the determination of the effectiveness of Sisal fibers on the resistance characteristics of two types of clay soil. The results showed that the incorporation of fibers into the matrix had positive effects on the strength parameters and slope stability.

- **Grave lateritic**

The incorporation of the three fibers at different contents causes an increase in the CBR index of the composites for a fiber content of 1% and a decrease for a



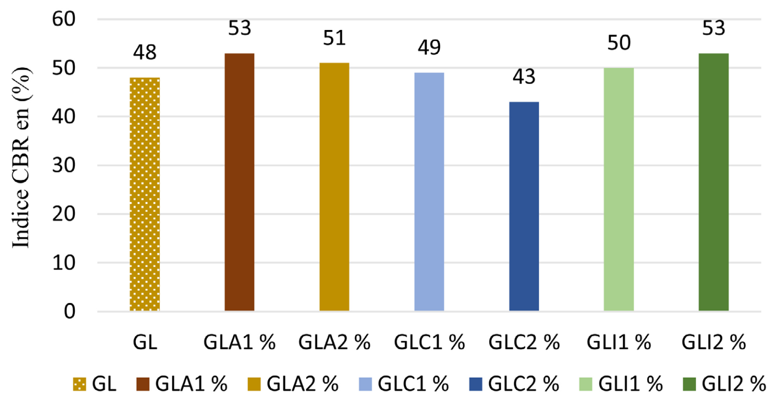
Graph 8. CBR values of bar soil + plant fibers at 1% and 2%.

content of 2% compared to the CBR of the soil in its natural state (Graph 9). Pineapple fibers incorporated at 1% into the soil increase the CBR value of the reinforced soil by 10%. With cyperus and imperata fibers, the strength gains are very low, around 4%. The incorporation of pineapple and cyperus fibers into this soil at a content of 2% does not significantly improve the mechanical characteristics of the matrix soil. On the other hand, we observe a gain of 10% with imperata fibers. Thus, for lateritic gravel at 1% fiber content, pineapple fibers offer better gain when incorporated into the soil compared to other fibers, likewise for imperata fibers at 2% content.

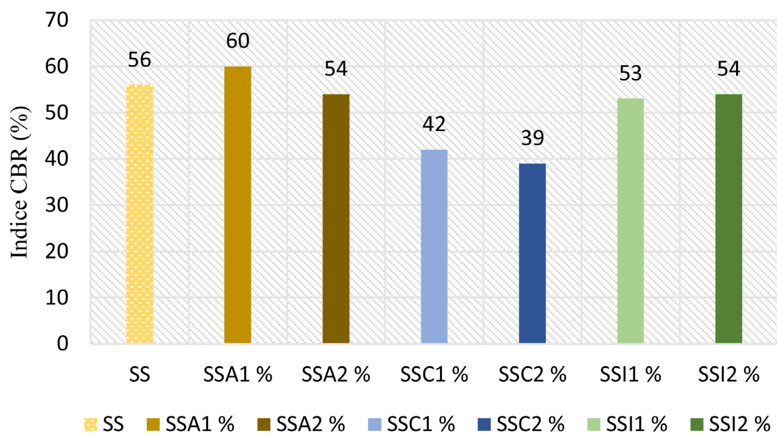
- **Silty sand**

Only pineapple fiber incorporated in a content of 1% offers a strength gain of 7%. As for the other fibers, their incorporation into the soil at both percentages rather reduced the CBR compared to the soil in its natural state, which does not offer a gain in the resistance of this material (Graph 10).

These results obtained with silty sand could be justified by the non-adhesion behavior of the materials. This reflects the treatments carried out by researchers Bateni F *et al.* [17] on the fibers from empty oil palm fruit clusters (OPEFB) in composite with silty sand.



Graph 9. CBR values of lateritic gravel + plant fibers at 1% and 2%.



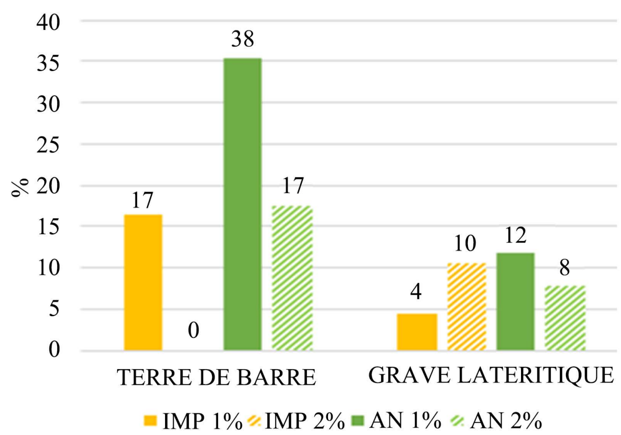
Graph 10. CBR values of silty sand + plant fibers at 1% and 2%.

From all of the above, it appears that at 1% fiber incorporation, there is an improvement in bar soil and lateritic gravel with the different fibers. A drop in the CBR value of the mixture of silty sand with cyperus and imperata fibers, on the other hand an improvement of 7.14% with pineapple fiber. At 2%, bar soil retains a good proportion of its mechanical characteristics when mixed with pineapple fibers. Composite materials based on silty sand and lateritic gravel do not perform well with plant fibers. Also this behavior of plant fibers in their natural state on powdery soils has been noticed by certain researchers in particular Z. Khelifi, et al from the University of Tlemcen (Algeria) [18] as does F. Touchard *et al.* [19] who advocates a study of the microstructure of the fibers to glimpse their mechanical behavior.

The following **Graph 11** provides a synoptic presentation of the gains for all composite materials.

At the end of the improvement study by three different plant fibers (cyperus, imperata and pineapple at 1% and 2%) of three types of soil commonly used in road geotechnics (bar earth, lateritic gravel, silty sand, a more in-depth analysis allows the following interpretations to be made:

- The cyperus influenced the characteristic resistance of the materials, by improving the bar earth and the lateritic gravel at 1% content and by making the silty already at 1% and 2% for all matrices lose their initial resistance. This result could be due to the tubular structure of cyperus stems. During the immersion of the test pieces, they would have absorbed water; which could encourage the inflation and decline of the value of the CBR.
- Imperata, used as a reinforcing element in earth matrices, offers a significant improvement to bar earth at 1% content and to grave at 2%. These improvements could be explained by the good adhesion between the materials and the rot-proof nature of imperata.
- Pineapple fiber mixed with the materials resulted in improved composites. Bar land and bass have been improved to very remarkable proportions. These results with pineapple fibers could be explained by the fibrous structure of pineapple leaves to resist breaking and their difficult decomposition.



Graph 11. Comparison of variations in gains according to materials.

- The grainy structure of the silty sand did not promote good adhesion with the plant fibers. The addition of fibers, particularly at 2% fiber content, made the material more porous, therefore causing a reduction in the mechanical characteristics of the materials under the effect of porosity.
- Laterite severity was improved by up to 12% by pineapple fibers with a fiber incorporation percentage of 1%.
- Bar earth was the best improved material with the three types of fibers at a mass content of 1%. The texture of the bar clay with the large proportion of fine elements would have favored good adhesion with the different fibers.

Ultimately, the bar clay studied (GTR A2 class) was more influenced by the addition of plant fibers than the other sourced materials. Of the three plant fibers, pineapple fibers behave as a good reinforcing element for the three types of matrix materials better than the other two fibers as some researchers have also noted [3] [6] [8] [20].

5. Conclusion

This exploratory study of the use of plant fibers in road technology aimed to promote local materials and optimize soil reinforcement processes using plant fibers to improve the mechanical characteristics of these materials. Three types of plant fibers were used to reinforce three road materials. It appears from the study that for the CBR index, pineapple fibers had more influence on all materials and even more on bar soil with a gain of 381% for a mass content of 1% at a length of 2.5 cm. Cyperus and imperata fibers did not have a great effect on soil improvement. The silty sand was not known after the addition of fibers of imperata cylindrica, and cyperus articulatus. This work will be continued with an expanded study of the influence of pineapple fibers on different barren soil type soils.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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