

Physico-Mechanical Characterisation of an Earth Bar and Bamboo Fiber Composite Material for Road Construction

Yvette Tankpinou Kiki^{1*}, Koffi Judicaël Agbelele², Fernando Kpomahou², Georgette Monleme³

¹Processes and Technological Innovation Laboratory (LaPIT), National University of Science, Technology, Engineering and Mathematics (UNSTIM), Lokossa, Benin

²Multidisciplinary Research Laboratory for Technical Education (LARPET), National University of Technological Sciences, Engineering and Mathematics, Lokossa, Benin

³Civil Engineering Test and Study Laboratory (L2EGC), National University of Technological Sciences, Engineering and Mathematics, Abomey, Benin

Email: *yvettetankpinou@gmail.com

How to cite this paper: Kiki, Y.T., Agbelele, K.J., Kpomahou, F. and Monleme, G. (2025) Physico-Mechanical Characterisation of an Earth Bar and Bamboo Fiber Composite Material for Road Construction. *Open Journal of Composite Materials*, 15, 31-43. <https://doi.org/10.4236/ojcm.2025.151002>

Received: August 20, 2024

Accepted: December 3, 2024

Published: December 6, 2024

Copyright © 2025 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0). <http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Road construction in Africa is faced with a shortage of quality materials, leading to delays and increased costs. Traditional materials, such as clay soils of the bar soil type, have inadequate properties for pavement sub-base layers, particularly in terms of bearing capacity. This study explores a composite material combining bar soil and bamboo fibers to improve the mechanical performance of bar soil, offering a sustainable and cost-effective solution. The Tori-Bossito bar soil was characterised by particle size analysis, Atterberg limits, Proctor compaction tests and the California Bearing Ratio (CBR). The results show that this material is a class A2 sandy-clay soil with a CBR of 18, which is insufficient for foundation layers requiring a CBR of over 30. To improve its performance, Sèmè-Kpodji bamboo fibers, 30 to 100 microns in diameter and 3 to 5 cm long, were incorporated at rates of 0.9% to 2.7%. The optimum mix, with 2.4% fiber, has a CBR of 35, a dry density of 1.92 t/m³ and a moisture content of 12.4%. This reinforced material is suitable as a base course for low-traffic roadways.

Keywords

Bamboo Fibers, Bar Soil, Sub-Base, Low Traffic, Mechanical Properties

1. Introduction

As essential pillars of economic and social development, transport infrastructure,

and in particular roads, play a key role in stimulating economic growth, employment and population mobility [1]. The quality and performance of road networks are a determining factor in the competitiveness of nations and the well-being of their citizens. According to a study by the Canadian Construction Association [2] the choice of base material and its stability are critical factors in ensuring pavement durability and wear resistance. However, in West Africa, until recently, lateritic gravel was the main source of materials for pavement construction. This dependence on traditional materials posed challenges in terms of the durability and performance of road infrastructure. To remedy this situation, new materials with the characteristics required for use in pavement layers need to be developed.

The current strategy is to strengthen the local materials available so that they can be used effectively. Bar soil and bamboo are abundant natural resources in almost all regions of Benin. Using these local materials would reduce transport costs and promote a circular economy. All reinforcement techniques (fiber reinforcement, lime or cement treatment, etc.) can be used [3] [4] all have the same objective: to improve the mechanical properties of the raw material so that it can be used in construction. According to [4], the presence of fibers counteracts the shrinkage and swelling responsible for cracks, thereby improving the mechanical strength of bar soil. The incorporation of plant fibers to produce a composite material is therefore an area of research being explored by researchers [3] [5]-[8]. According to INRAB, the main African producers of bamboo are Ethiopia, Benin and Burundi, which form the top three. In West Africa, Benin is the leading producer of bamboo, according to the same source (INRAB). Composite materials based on bamboo fibers could be used in a variety of applications, ranging from road construction to the manufacture of panels and other construction elements [9]. This is also part of a relevant context of developing local resources, taking into account the availability of basic raw materials [10]. Plant fiber composites are currently in great demand in several sectors because of their biodegradability [11]. Their use not only reduces the carbon footprint of construction projects, but also creates economic opportunities for local communities [12]. This is the reasoning behind the use of certain natural fibers which, in addition to the direct advantage of reducing the negative impact on the environment [13]-[19] has interesting mechanical properties. What's more, these initiatives to add value to natural fibers are in line with sustainable development objectives, promoting a greener, more environmentally-friendly approach [20].

Reinforcing local materials such as bar soil with bamboo fibers is a promising strategy for improving road infrastructure in West Africa. These innovations contribute not only to the durability and resilience of roads, but also to the promotion of sustainable and cost-effective construction practices. By integrating these materials into construction projects, it is possible to create more robust infrastructures, stimulate the local economy and meet today's environmental challenges [21].

This work is a contribution to the study of the improvement of local materials

for road construction in West Africa, in particular through the incorporation of bamboo fibers. The aim is to assess the impact of incorporating bamboo fibers on the mechanical performance of the composite material.

2. Materials and Methods

This section presents the materials and methodology used in this work.

2.1. Materials

Our study focuses on the development of an innovative composite material for use as a sub-base in low-traffic pavements. The composite material is made from bamboo fibers embedded in bar soil.

2.1.1. Bar Land

The bar soil (**Figure 1**) used in this study comes from the locality of Tori-Bossito, located in the Atlantic department of the Republic of Benin. The sampling site (**Figure 2**) lies between latitudes $6^{\circ}25'$ and $6^{\circ}37'$ North and longitudes $2^{\circ}11'$ and $2^{\circ}17'$. This area, with a surface area of 328 km^2 , represents 10% of the total surface area of the Atlantic department. The map below shows the exact location of the sampling site.



Figure 1. Bar land.

2.1.2. Bamboo Fibers

The bamboo fibers used in this study were collected in Sèmè-Kpodji, a commune in the Ouémé department of the Republic of Benin. The commune lies between latitudes $6^{\circ}22'$ and $6^{\circ}28'$ North and longitudes $2^{\circ}28'$ and $2^{\circ}43'$ East, and covers an area of 250 km^2 , or approximately 0.19% of the country's total surface area. The bamboos are harvested, and the fibers are then extracted using the manual method according to [22]. **Figure 3** and **Figure 4** show a bamboo field, the bamboo stalks and the fiber extraction method [23].

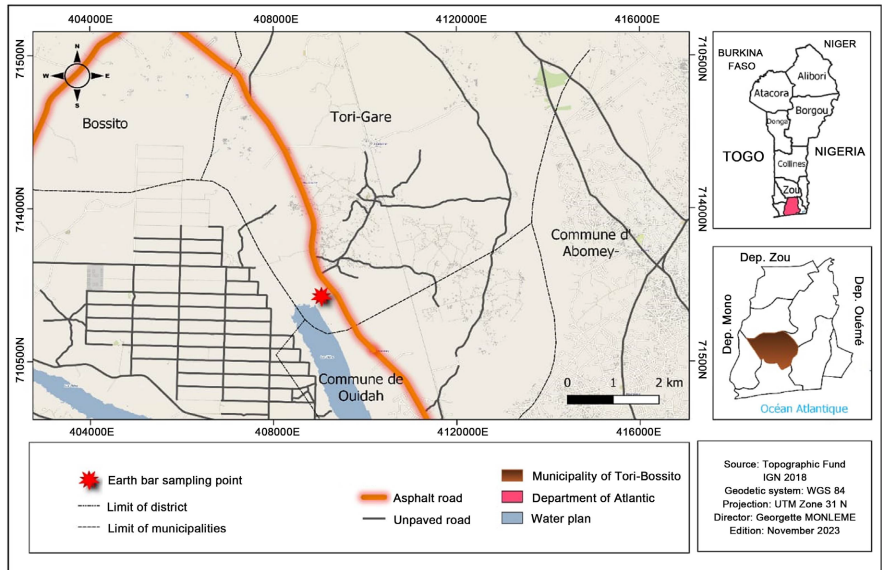


Figure 2. Site where the bar soil was taken.

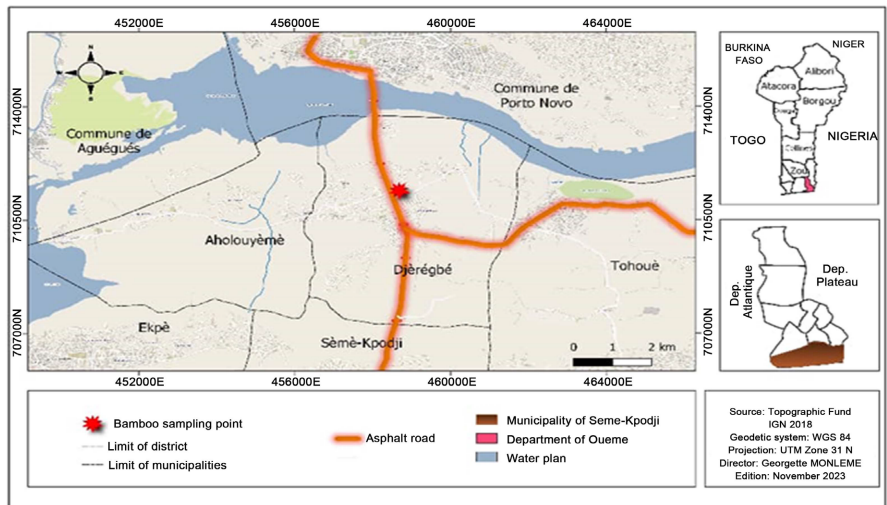


Figure 3. Bamboo harvesting site.



Figure 4. Bamboo fiber extraction.

2.2. Materials

Physical and mechanical characterisation tests were carried out on the composite material. The bar soil was identified according to the Guide to road earthworks (GTR) classification, based on the chart shown in **Figure 5**, and the dry density was determined following the modified Proctor test in accordance with standard NF P94-093.

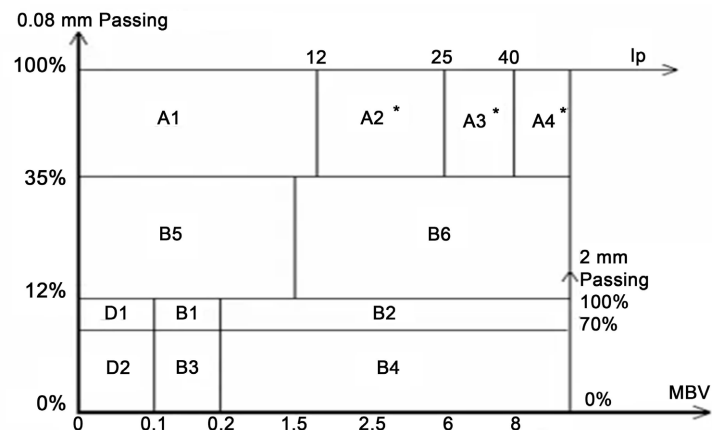


Figure 5. GTR classification.

2.3. Methodology

Bar soil was identified on the basis of the GTR classification. Various formulations of bar soil-bamboo fiber composites were then developed at different fiber contents (0.9%, 1.2%, 1.5%, 1.8%, 2.1%, 2.4% and 2.7%), taking into account previous studies. The bamboo fibers used are between 3 and 5 cm long and have a diameter of between 30 and 100 microns. This commonly used treatment method involves mixing bar soil with bamboo fibers prior to their use. The mixtures were homogenised over a period of 5 minutes. The fibers were then added by mixing. The prepared composite material was placed and compacted immediately after mixing. For each mix, a quantity of 6 kg of bar soil was taken. A mass of fiber corresponding to the fiber content was then subtracted from this 6 kg, so that the total mass of the fiber-bar soil mixture remained at 6 kg. The amount of water added was determined to promote optimum compaction. Two types of tests were carried out to assess the properties of the composite material: The Proctor test and the CBR test. Finally, prismatic briquettes measuring $16 \times 4 \times 4 \text{ cm}^3$, shown in **Figure 6**, were manufactured to enable shrinkage and mass loss tests to be carried out. These tests enabled the behavior of the composite material to be analysed in detail.

3. Results and Discussion

The results of the physico-mechanical tests are presented and analysed in this section, enabling the performance and characteristics of the materials studied to be assessed.

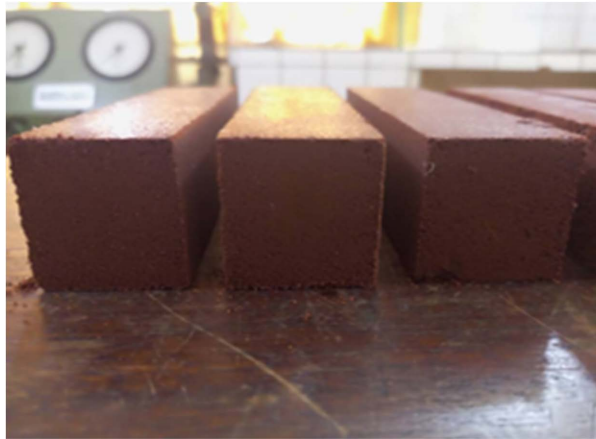


Figure 6. Composite briquettes $16 \times 4 \times 4 \text{ cm}^3$.

3.1. Physical Characterisation of Bar Clay Material

3.1.1. Particle Size Analysis Test

The results of the particle size analysis are shown in Figure 7.

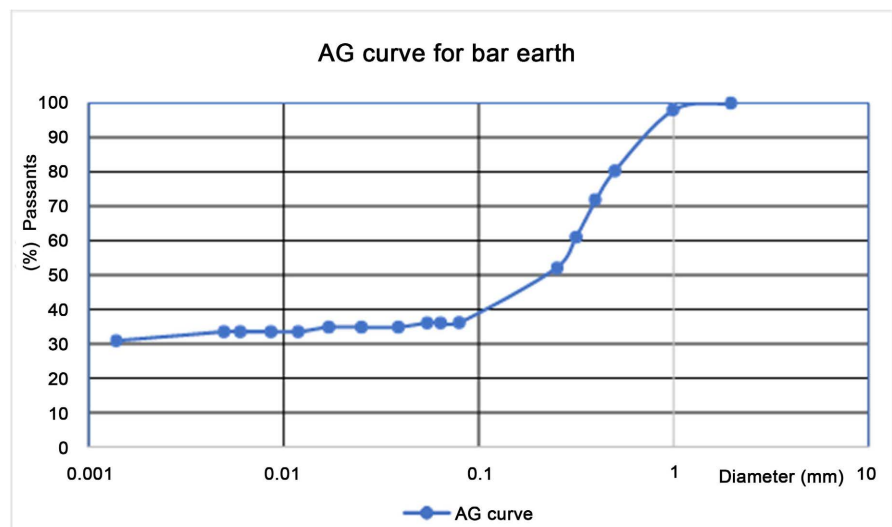


Figure 7. Particle size analysis curve.

The particle size analysis curve (Figure 7) shows that the material has a continuous particle size. It indicates a 0/2 gradation and a percentage passing the 80-micron sieve of 36.16. According to the road earthworks guide (GTR), the soil studied is class A.

3.1.2. Atterberg Limits

In order to assess the plasticity and cohesion properties of the material, the values of the Atterberg limit tests are presented in Table 1.

A plasticity index (PI) of 19.3 indicates a material that complies with the requirements for road base construction. With a PI of between 12 and 25, the material is not very plastic (sand-clay).

Table 1. Atterberg limit values.

Material	W _L	W _P	I _P
Bar land	41.30	22	19.3

3.1.3. Organic Matter Content

The impact of organic matter on the properties of clays is undeniable. Its content directly influences the quality of these materials. This is why a classification of clay soils according to their organic matter content has been established. At the end of the test, the organic matter content of the material was 0.149% < 3%. The material can therefore be used in civil engineering constructions.

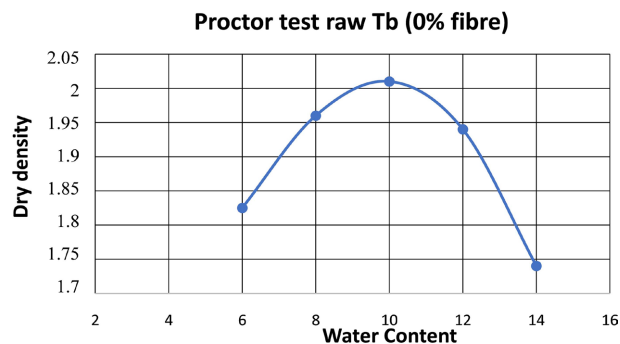
3.1.4. Methylene Blue Test

The methylene blue value obtained for the bar soil material is 0.57, classifying this material as sandy-clay with a low sensitivity to water.

All in all, analysis of the results obtained during the physical characterisation tests on the bar soil sampled at Tori-Bossito shows that it is a class A2 soil according to the GTR guide. Then, according to Casagrande's classification, it is a soil with low plasticity. Finally, analysis of its chemical composition reveals an inorganic character. Taken together, these properties lead us to classify the Tori-Bossito bar soil as a sandy-clay soil with low cohesion and low moulding capacity.

3.2. Mechanical Characterisation

3.2.1. Modified Proctor Test

**Figure 8.** Proctor curve for raw bar soil.

The maximum dry density at the end of the test is 2.01 t/m³ and the optimum moisture content is 10.08% (**Figure 8**).

3.2.2. Californian Bearing Ratio (CBR) Test

The data obtained from the modified Proctor test is then used as the basis for carrying out the CBR test according to the number of blows, the stress-strain curve being that shown in **Figure 9**.

The CBR value at 95% of the OPM after immersion for 96 hours is 18. Bar soil therefore has a low load-bearing capacity and needs to be improved before it can be used as a pavement layer. All in all, from the point of view of mechanical

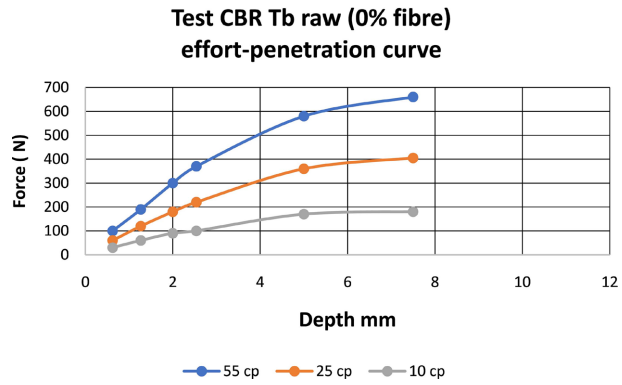


Figure 9. Effort-penetration curve for raw Tb (0% fiber).

characteristics, the bar soil has a CBR index of 18 at 95% of the OPM, which is insufficient for a sub-base layer (25 for traffic class T1 and 35 for classes [T4 - T5]). From these initial analyses, it can be seen that bar soil in its natural state cannot be used as a road base.

3.3. Mechanical Characteristics of the Composite Material

As bar soil has a low bearing capacity, it is necessary to improve its bearing capacity under the best compaction conditions if it is to be used for road construction.

To this end, seven blends were produced, as shown in Table 2 below:

Table 2. Percentage of mixtures.

Mixture number	Percentage of fibre
Mix 1	0.9%
Mix 2	1.2%
Mix 3	1.5%
Mix 4	1.8%
Mixture 5	2.1%
Mix 6	2.4%
Mix 7	2.7%

The results obtained on the mixtures are summarised in Table 3.

Table 3. Summary of results from Proctor and CBR tests on mixes.

	M1	M2	M3	M4	M5	M6	M7
Maximum density $\rho_{dmax} (t/m)^3$	1.97	1.95	1.95	1.96	1.94	1.92	1.95
Optimum water content (w_{opt} in %)	12.8	11.2	12.5	12.4	12.5	12.4	12.3
CBR at 95% of OPM	12	12	16	17	22	35	27

Figure 10 shows the variations in the dry density and water content of the composite material as a function of the percentage of fiber incorporated in Bar Earth.

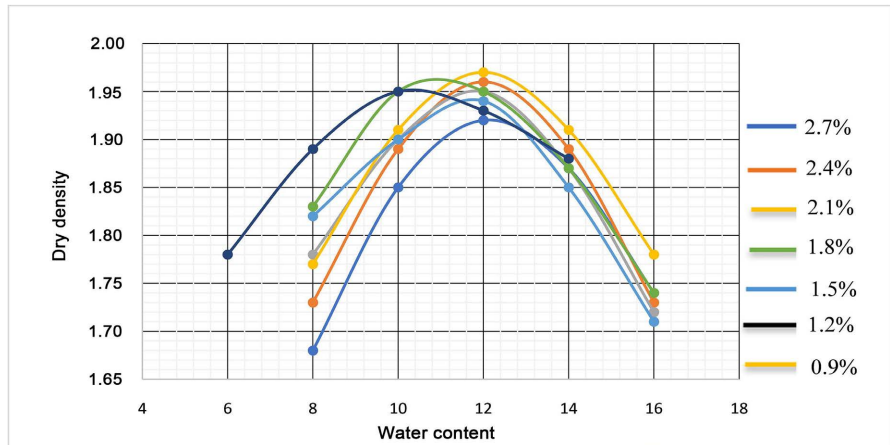


Figure 10. Proctor curve for raw soil and mixtures.

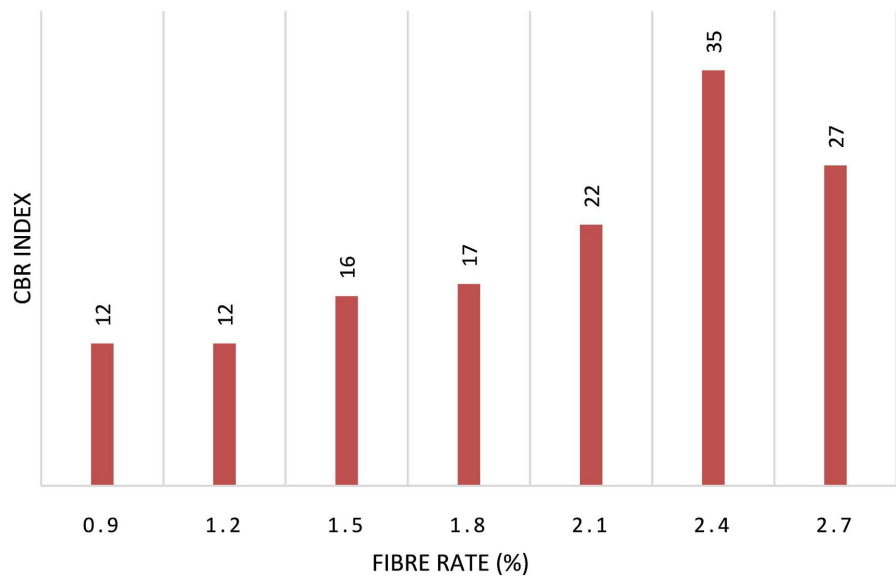


Figure 11. CBR indices as a function of fiber content.

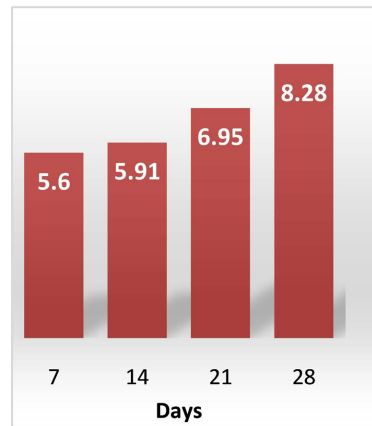
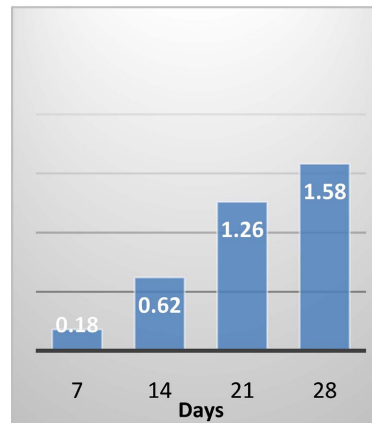
The incorporation of bamboo fibers into the composite material leads to a significant increase in the CBR index (Figure 11), reaching a maximum of 35% before decreasing; this suggests an optimum zone for the reinforcement of the material, confirming the results of this research [24]-[27].

3.4. Behavior of Composite Materials

Shrinkage and mass loss test Table 4 and Figure 12 and Figure 13 show the results of the shrinkage and loss of mass of the composite material as a function of time.

Table 4. Summary of mass loss and shrinkage tests.

Time	7 days	14 days	21 days	28 days
Mass loss (%)	5.60	5.91	6.95	8.28
Shrinkage (%)	0.18	0.62	1.26	1.58

**Figure 12.** Mass loss.**Figure 13.** Shrinkage.

The results show a positive correlation between time and shrinkage, as well as loss of briquette mass. This phenomenon is explained by the progressive loss of water contained in the material, due to natural evaporation. The clay composition of bar clay is generally likely to generate cracks during drying. Nevertheless, the absence of cracks in briquettes made from our composite material indicates remarkable stability in the face of aging. We conclude that our material does not show any degradation [28] and therefore does not show any alarming signs of aging during the observation period.

4. Conclusion

This study explores the physical-mechanical properties of an innovative composite material based on bar soil and bamboo fibers, considered as an alternative

solution for the sub-base layers of low-traffic roadways. The tests carried out confirm the A2 classification of Tori-Bossito bar soil. Reinforced with 2.4% bamboo fiber, the composite material has a CBR rating of 35, exceeding the minimum requirements for T1 road sub-bases. These results suggest the potential of this composite material as a local and sustainable solution to the challenges of scarcity of conventional materials in road construction in Benin. The adoption of this material could contribute to the sustainable development of road infrastructure in Benin, promoting the resilience and economic efficiency of pavements, while meeting the country's socio-economic challenges. This study opens up promising prospects for more ecological and efficient road construction, as part of a circular economy approach that makes the most of local resources.

Conflicts of Interest

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

References

- [1] (2014) La politique de la concurrence et ses effets macroéconomiques: Une fiche d'information© OCDE 2014.
- [2] Association canadienne de la construction. Association canadienne de la construction. <https://www.cca-acc.com/fr/>
- [3] Abessolo, D., Didier, F. and Biwolé, A. (2021) Valorisation des matériaux locaux: Étude de l'effet des fibres de bambou sur les propriétés des Blocs de Terre Comprimée utilisés dans la construction.
- [4] Christine, D.A., Séraphin, D.A., Olivier, B.M. and Edjikémé, E. (2018) Effet de l'addition de fibres de coco traitées à la potasse sur les propriétés mécaniques des matériaux de construction à base d'argile-ciment. *European Scientific Journal ESJ*, **14**, 104. <https://doi.org/10.19044/esj.2018.v14n36p104>
- [5] Faruk, O., Bledzki, A.K., Fink, H. and Sain, M. (2012) Biocomposites Reinforced with Natural Fibers: 2000-2010. *Progress in Polymer Science*, **37**, 1552-1596. <https://doi.org/10.1016/j.progpolymsci.2012.04.003>
- [6] Abessolo, D., Biwolé, A., Didier, F., Morino, B., Ganou Koungang, B.M. and Yebga, B. (2020) Effets de la longueur et de la teneur des fibres de bambou sur les propriétés physi-comécaniques et hygrosopiques des Blocs de Terre Comprimée (BTC) utilisés dans la construction. *Afrique Science Revue Internationale des Sciences et Technologie*, **16**, 13-22.
- [7] Adagbe, M.T. (2021) Utilisation de la terre renforcée par des tiges de paille de riz comme matériau des éléments porteurs des bâtiments armés avec le rônier.
- [8] Dessalegn, Y., Singh, B., Vuure, A.W.v., Badruddin, I.A., Beri, H., Hussien, M., *et al.* (2022) Investigation of Bamboo Fibrous Tensile Strength Using Modified Weibull Distribution. *Materials*, **15**, Article No. 5016. <https://doi.org/10.3390/ma15145016>
- [9] Kumar, T. (2018) Libre acc è s Enquête sur l'inclusion aléatoire de fibres de bambou sur un sol ordinaire et son effet sur la valeur CBR.
- [10] Chéïssou, B., Tamou, K., Crespin, J.M., Yabi, P. and Edjrossè, G. (2023) Utilisation d'additifs à base de produits forestiers non ligneux pour la stabilisation écologique de la terre crue: Cas de la noix de Parkia Biglobosa et de Vitellaria Paradoxa.
- [11] Marandi, S.M., Bagheripou, M.H., Rahgozar, R. and Zare, H. (2008) Strength and Ductility of Randomly Distributed Palm Fibers Reinforced Silty-Sand Soils. *American*

- Journal of Applied Sciences*, **5**, 209-220.
<https://doi.org/10.3844/ajassp.2008.209.220>
- [12] Quenum, S.P., Kiki, Y.S.T., Agbelele, J.K., Yabi, C.P. and Adjovi, E.C. (2023) Influence of Some Plant Fibers on the Mechanical Performance of Composite Materials. *Open Journal of Civil Engineering*, **13**, 814-826.
<https://doi.org/10.4236/ojce.2023.134053>
- [13] Zornberg, J.G. and Roodi, G.H. (2021) Use of Geosynthetics to Mitigate Problems Associated with Expansive Clay Subgrades. *Geosynthetics International*, **28**, 279-302.
<https://doi.org/10.1680/jgein.20.00043>
- [14] Nkotto, L.I.N., Kamgang, G.D., Tiewa, J., Kanda, J.S. and Loweh, S.S. (2020) Caractérisation des blocs produits par addition des fibres de coco et des matériaux de construction à base de latérite ciment.
- [15] Jahandari, S., Saberian, M., Zivari, F., Li, J., Ghasemi, M. and Vali, R. (2017) Experimental Study of the Effects of Curing Time on Geotechnical Properties of Stabilized Clay with Lime and Geogrid. *International Journal of Geotechnical Engineering*, **13**, 172-183. <https://doi.org/10.1080/19386362.2017.1329259>
- [16] Omrani, H., Hassini, L., Benazzouk, A., Beji, H. and ELCafsi, A. (2020) Elaboration and Characterization of Clay-Sand Composite Based on Juncus Acutus Fibers. *Construction and Building Materials*, **238**, Article ID: 117712.
<https://doi.org/10.1016/j.conbuildmat.2019.117712>
- [17] Laverde, V., Marin, A., Benjumea, J.M. and Rincón Ortiz, M. (2022) Use of Vegetable Fibers as Reinforcements in Cement-Matrix Composite Materials: A Review. *Construction and Building Materials*, **340**, Article ID: 127729.
<https://doi.org/10.1016/j.conbuildmat.2022.127729>
- [18] Sujatha, E.R., SaiSree, S., Prabalini, C. and Aysha Farsana, Z. (2017) Influence of Random Inclusion of Coconut Fibres on the Short-Term Strength of Highly Compressible Clay. *IOP Conference Series: Earth and Environmental Science*, **80**, Article ID: 012056. <https://doi.org/10.1088/1755-1315/80/1/012056>
- [19] Abdelouahed, A., Kechkar, C., Hebhouh, H., Merzoud, M. and Boukhatem, G. (2023) Enhancing the Performance and Durability of Eco-Friendly Mortar with Diss Fibers (*Ampelodesmos mauritanicus*). *Revue des composites et des matériaux avancés*, **33**, 219-226. <https://doi.org/10.18280/rcma.330402>
- [20] Joshi, S. and Patel, S. (2021) Review on Mechanical and Thermal Properties of Pineapple Leaf Fiber (PALF) Reinforced Composite. *Journal of Natural Fibers*, **19**, 10157-10178. <https://doi.org/10.1080/15440478.2021.1993487>
- [21] Souck, J.L., Tchotang, T. and Kenmeugne, B. (2022) Influence of the Age of Bamboo Culm and Its Vertical Position on the Technological Properties of Bamboo Fibers: A Case of *Bambusa vulgaris* Species from Cameroonian Culture. *Open Journal of Composite Materials*, **12**, 98-110. <https://doi.org/10.4236/ojcm.2022.123008>
- [22] Liang, S.X. (2012) Etude de comportement en fatigue des composites renforcés par fibres végétales: Prise en compte de la variabilité des propriétés.
https://www.researchgate.net/publication/278643415_Etude_de_comportement_en_fatigue_des_composites_renforces_par_fibres_vegetales_prise_en_compte_de_la_variability_des_proprietes
- [23] Ambekar, A.M., et al. (2023) Effect of Seawater Absorption on Mechanical and Flexural Properties of Pineapple Leaf Fiber Reinforced Epoxy Nanoclay Composites. *ES Materials & Manufacturing*, **22**, 1067.
<https://www.espublisher.com/journals/article/details/1067>
- [24] Nyior, G.B. and Mgbeahuru, E.C. (2018) Effects of Processing Methods on

- Mechanical Properties of Alkali Treated Bagasse Fibre Reinforced Epoxy Composite. *Journal of Minerals and Materials Characterization and Engineering*, **6**, 345-355. https://www.scirp.org/pdf/JMMCE_2018051015020484.pdf
- [25] Modjonda, Souaibou, Etienne, Y. and Raidandi, D. (2023) Thermal and Mechanical Characterization of Compressed Clay Bricks Reinforced by Rice Husks for Optimizing Building in Sahelian Zone. *Advances in Materials Physics and Chemistry*, **13**, 177-196. https://www.scirp.org/pdf/ampc_2023103016285824.pdf
- [26] Kaho, S.P., *et al.* (2020) Development of a Composite Material Based on Wood Waste Stabilized with Recycled Expanded Polystyrene. *Open Journal of Composite Materials*, **10**, 66-76. https://www.scirp.org/pdf/ojcm_2020072914134260.pdf
- [27] Adagbe, M.T. (2021) Utilisation de la terre renforcée par des tiges de paille de riz comme matériau des éléments porteurs des bâtiments armés avec le rônier. <https://theses.hal.science/tel-03551654v1/document>
- [28] Perrier, A. (2017) Influence du vieillissement hydrique sur le comportement mécanique de l'interface fil/matrice dans les composites chanvre/époxy.