Scientific Research Publishing

Open Journal of Civil Engineering, 2023, 13, 706-722
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

The Technique of the Tri-Layer Coating: An Effective Solution for the Protection of Earthen Constructions

Sinko Banakinao[1,2], Soviwadan Drovou[2,3], Komlan Lolo[2,3], Kodjo Attipou[2,3]

[1]Department of Civil Engineering, Polytechnic School of Lomé (EPL/UL), University of Lomé, Lomé, Togo
[2]Laboratory of Structures and Mechanics of Materials (LaS2M), University of Lomé, Lomé, Togo
[3]Department of Mechanical Engineering, Polytechnic School of Lomé (EPL/UL), University of Lomé, Lomé, Togo
Email: kodjo.attipou@yahoo.fr

How to cite this paper: Banakinao, S., Drovou, S., Lolo, K. and Attipou, K. (2023) The Technique of the Tri-Layer Coating: An Effective Solution for the Protection of Earthen Constructions. *Open Journal of Civil Engineering*, **13**, 706-722.
https://doi.org/10.4236/ojce.2023.134047

Received: October 26, 2023
Accepted: December 18, 2023
Published: December 21, 2023

Abstract

The problem with earth constructions is their low resistance to water. Step by step, the water degrades the exterior facings of the structures and ends up creating zones of weakness through the structures, making them collapse and creating enormous socio-economic problems, especially in rural areas. The solutions proposed to date, like the use of straw, cow dung, boiled skins, banana leaves, tar, cement soil, have shown their limits. Generally, the poor adhesion between the protected material and the protective layer means that the latter always ends up peeling off. This work, which is inspired by the traditional practice where plant tannins are used to brush the earthen walls to waterproof them, proposes a tri-layer coating composed of soil, powder and hydrolysable tannins extracted from the stem bark of Bridelia. This work focuses on the geotechnical characterization of the soil, the extraction of hydrolysable tannin, the manufacture of the micro-coating, the resistance tests carried out on the micro-coating, the technique of implementation and the test of evaluation of the performance of the tri-layer coating. The results obtained show that not only does the tri-layer coating adhere perfectly to the layer to protect, but it also waterproofs it and protects it against shocks.

Keywords

Tri-Layer, Tannin, Coating, Soil, Earthen Constructions

1. Introduction

It is interesting to notice that in this twenty-first century, characterized by innovation and cutting-edge technologies, an ancestral construction process continues to bring to nowadays' builders, efficient responses to their needs: aesthetics, durability, mechanical resistance, fire resistance, in particular. Many age-old buildings have provided proof that masonry and earthen coatings have the characteristics mentioned above and make them last for a long time.

However, the more recent history of the pathology of masonry facades has also shown how a drift in the quality of the products or their use can lead in a few years to the deterioration of the structures, sometimes, to their disappearance.

If in developed countries, traditional earthen construction techniques have evolved a lot with numerous regulatory and normative texts codifying with more and more precision on earthen products, the conditions of their use, and the performances of the walls built, in Africa, ancestral empiricism are still carried out. It is for this reason that many African researchers are now looking at local construction materials to define regulatory and normative texts. It is in this context that this work fits, which is inspired by the traditional practice where plant tannins are used to coat earthen walls to waterproof them and to propose a system of protection of earthen constructions in tri-layer coating made of soil, powder and hydrolysable tannins extracted from the stem bark of Bridelia. To propose a technique for the protection of earthen constructions that will last over the long term, it is necessary to master the problem of earth constructions, to identify and diagnose the shortcomings and inadequacies of the classic and traditional protection techniques commonly practiced, and to design a methodology which does not deviate from traditional practices and whose results are effective and scientifically measurable technical parameters.

2. The Problem of Earth Constructions

There are hardly any professionals in the earthen construction industry in Europe or in Africa. But, for years, they have been attempting to save lost know-how, to revalue the first building material in history, modernize its image to recognize its many assets for the buildings of tomorrow. This is indeed an abundant eco-material [1] [2] [3], which requires much less energy for its manufacture (than lime and cement), very few emissions of dioxide of carbon and which does not generate waste and whose use has positive impact on the environment [4].

Its high density gives it valuable thermal inertia qualities for storing solar heat and its slow release makes it very comfortable in summer. Earthen walls remarkably regulate the humidity of the indoor air thanks to their permeability to water vapor and are a good sound insulator. Contrary to preconceived ideas, it is a material that resists strongly during ages and offers the widest range of sizes, textures, and colors. It can be used in different ways, which is why it has been able to remarkably accompany all civilizations from antiquity to modern times. Through the world heritage of the traditions of earthen construction, there are many techniques of construction with an infinite number of variants adapted to the quality of the soil [5].

Despite all these advantages and its availability, African's traditional techniques of earthen construction have not benefited from the technological advances that the same material has benefited in the developed countries (use of standards, mechanization, research centers, organisms of control). The techniques of earthen construction are left to ancestral empiricism. The few innovations which have been inspired by technologies in developed countries are not adapted to the realities of the rural world in Africa where soil is the main construction material. This technological insufficiency has left behind the ancestral pathologies of construction which discourage the choice of earth structures in favor of concrete and steel despite their increasing cost. A recent study carried out in Togo on the pathologies of earthen constructions [6] has revealed that three types of pathologies affect the coatings of earthen constructions:

- The lack of mechanical resistance of the body of the coating causing it to crumble (**Figure 1**),
- The lack of waterproofing of the coating paint causing the surface layer to wash away (**Figure 2**),
- And the lack of adhesion of the coating to the support which most often causes the body of the coating to peel off (**Figure 3** and **Figure 4**).

Figure 1. Crumble of the coating.

Figure 2. Leaching of the surface layer in bitumen.

Figure 3. Peeling of the body of the coating.

Figure 4. Typical examples of the ruin of earthen constructions.

In Togo, as in several African countries, the essential and yet often poorly understood aspect in studies of earthen construction is sustainability. When the damage to earth buildings is carefully examined, as well as the pathologies of the supporting structure or the coating, it appears that all these pathologies have the same origin, which is water.

Indeed, water is the first enemy of earthen structures. Their facades are exposed to sun and rain [7]. Under the rain, water wets the soil, reduces internal cohesion, leaches fine soil particles from the exterior walls which eventually end up thinning and cracking. In addition, when the support wall is protected by a coating layer, the cohesion at the interface of the wall of support and the protective layer being weaker than in each material, the cohesion at the interface is canceled more quickly in the presence of water, hence the phenomenon of peeling off the body of the coating. Examination of the peeled samples shows that the water content at the interface is greater than the water content in the body of the coating or in the wall of support. This phenomenon also comes from temperature differences (low in the rain and high in the sun after the rain) which create thermal stresses at the interface which end up peeling off the body of coating from the supporting wall. The combination of all these phenomena, sooner or later, ends up causing the ruin of the structure (**Figure 4**).

The solution of the tri-layer coating that is proposed in this article is designed and produced in such a way that each layer of the coating provides the solution to one of the three types of pathologies of conventional coatings for earthen constructions (**Figures 1-4**).

Generally, coatings are made up of a binder (lime, plaster, Portland cement or clay) and mineral fillers (aggregates such as sand or dust of marble) in a ratio of approximately 1/3 binder for 2/3 mineral fillers. The addition of pigments (coloring fillers) is not essential, but it depends on the desired effect.

The purpose of coating has always been to protect the support against physical and climatic attacks and to ensure the impermeability of the building. The aesthetic function is achieved by the color and appearance of the mortar of the finishing layer. It has no structural role. The coating is a guarantee of durability for all masonry works or supports resulting from filling techniques.

3. Equipment, Materials, and Method

3.1. Equipment and Accessories

From the treatment of removing the bark of the Bridelia through the extraction of tannin, to the construction of an experimental wall, a certain number of equipment and accessories were used:

- An oven for accelerated and controlled drying,
- Kitchen knives to crumble the bark into tiny pieces,
- A grinder equipped with different sieves (0.25 mm, 2 mm, and 5 mm),
- Sieves,
- A balance of precision of 0.01 g,
- Plastic vases of 1 liter, 25 liters, 45 liters and 80 liters for the treatment and conservation of the solution of the tannin of Bridelia,
- Aluminum basins to vaporize the solution of the tannin,
- A gas burner for heating,
- Small equipment: shovels, trowels, pickaxes, gametes, rulers.

3.2. Raw Materials Used in the Manufacture of Tri-Layer Coating

The raw materials used in the manufacture of the tri-layer coating were soil, stem bark of Bridelia, and water. The soil used is clayey sand of medium plasticity. The identification of this soil is made by standardized geotechnical tests [8] [9] such as: analysis of size of particle [10] [11], limit of liquidity [12], and limit of plasticity [13].

3.2.1. Tannic Extraction Methodology

Bridelia (**Figure 5**) is one of the plants highly rich in tannin, like the leaf sheath of sorghum, the bark of false logwood and the pod of Nere [14] [15] [16] [17]. The stem bark of Bridelia (**Figure 6**) were crushed (**Figure 7**), to produce powder. This powder (**Figure 8**) was used for the extraction of the tannin. The process of the extraction is artisanal and can be summarized in three steps.

Figure 5. Plant of Bridelia.

Figure 6. Bark of Bridelia.

Figure 7. Preparation of the bark.

Figure 8. Powder of the bark.

First step: Imbibition of the powder of Bridelia and homogenization

The powder of Bridelia is imbibed in water in such a way of a ratio of 1 gram of powder for 8 grams of water. This imbibition is done gradually with homogenization with manual stirrer hand until the powder is completely dissolved in water. After dissolution of the powder in water, homogenization is done every 20 minutes to avoid the formation of powder bubbles in the solution. This operation can last a day. The solution is left to rest for at least 7 days while taking care each day to homogenize the solution at least once to allow the layer which floats on top of the mixture (**Figure 9**) to disperse in the solution. From the fourth day, the solution changes color.

Second step: Filtration

After seven days of imbibition, the tannins hydrolyze. The liquid which floats at the surface is siphoned off and the rest is pressed through a cotton cloth (**Figure 10**). The liquid obtained by siphoning plus that obtained after pressing were mixed and passed through a sieve of 0.08 mm. Thus, the filtrate obtained (**Figure 11**), is ready for vaporization.

The residues obtained with a sieve of 0.08 mm during filtration were dried then homogenized (**Figure 12**). Those residues are so-called sediments of the powder of Bridelia and were used in the composition of the tri-layer coating.

Figure 9. Layer floating at the surface.

Figure 10. Filtration with cloth.

Figure 11. Concentrated solution of tannins.

Figure 12. Sediments of the powder.

Third step vaporization of water by cooking

Hydrolysable tannins are obtained after the vaporization of water from the solution. This was done either by drying in the sun (natural vaporization) or using a machine capable of separating the water from the tannin (chemical absorption) or by heating. For the purposes of our work, the heating methods were adopted. The solutions were therefore heated using a gas cylinder (**Figure 13**) until a sticky viscous paste were obtained: this is the concentrated solution of hydrolysable tannins (**Figure 14**).

3.2.2. Manufacturing and Implementation of the Tri-Layer Coating

The tri-layer coating was made up of three layers: the bonding layer, the body of the coating and the protective layer (finishing coat).

The bonding layer

The bonding layer was 2 to 7 mm of thickness and was composed of 1/3 of the sediments of the powder of Bridelia, of 1/3 of moderately plastic soil with a granulometry of 0/2, and of 1/3 of tannin of Bridelia. The product obtained is liquid and was applied on the support in two or three successive passes; this to allow the body of coating to adhere to the support (**Figure 14**).

Figure 13. Vaporization by heating.

Figure 14. Hydrolysable tannins.

The coating body

The coating body was the second layer and was applied over the first layer after one to two hours. Its thickness varies from 1 to 2 cm. Its composition varies depending on the consistency of the soil used.

- 8% to 10% of the powder of Bridelia for 90% to 92% of clays, little and moderately plastic,
- 10% to 12% of the powder of Bridelia for 88% to 90% of silts, not very plastic,
- 7% to 9% of the powder of Bridelia for 91% to 93% of plastics clays.

The protective layer

The protective layer was the third and final layer. It was 5 to 7 mm of thickness. It waterproofs the structure and can also have a decorative role. It was made essentially from a concentrated solution of the tannin of the powder of Bridelia and was applied in two or three passes depending on the concentration of the solution of the tannin.

3.2.3. Methodology of the Control of Quality of the Tri-Layer Coating

Three types of tests were used to control the quality of the tri-layer coating: the simple compression test, the bending test, and the weather resistance test. The simple compression and bending test were both performed on specimens of 4 cm × 4 cm × 16 cm.

Simple compression and bending tests

- *Sample preparation*

The mixture (soil and powder of Bridelia) was mixed up and homogenized. A starting quantity of water which content was like optimum Proctor and in addition of the quantity of water to be absorbed by the powder of Bridelia was used to gradually moisten the mixture until the complete homogenization of the mortar. The quantity of water was adjusted in the case the mixture lacked workability. The mortar obtained was molded into two layers in a prismatic mold with three compartments of 4 cm × 4 cm × 16 cm of dimensions. The first layer was filled up to half of the mold and the cover was closed with pressure exerted manually, which pre-compressed the material. The second layer filled the mold topped with its slipcover, the cover was closed then an additional stress was exerted using a press so that the stress exerted by the cover plus the additional stress was equal to 3.5 MPa. The lid was removed, and the mold was unmolded after 24 hours. Fifty (50) were manufactured using the process described above. The manufactured samples were stored for at least 2 hours and then were dried in the open air until constant content of water was obtained. Twenty (20) additional samples, without the powder of Bridelia, were manufactured using the same process, for control purposes. This was to assess the influence of the binder (the powder of Bridelia) on the composite material obtained. The samples (**Figure 15**), once dried, were subjected to the bending test and the simple compression test.

- *Simple bending test*

This test was performed to define the resistance value of the powder of Bridelia considered as a binder. The test consisted in studying the tensile strengths of the samples of composite mortar (soil + powder of Bridelia). In such a mortar, the only variable was the nature of the binder. The resistance of the mortar was then considered to be significant of the resistance of the binder. The rupture of each sample in bending was carried out on a press [18] (**Figure 16**) then the bending stress was calculated by the formula:

Figure 15. Samples (4 cm × 4 cm × 16 cm).

Figure 16. Simple compression and bending tests.

$$R_f = \frac{1.5Fl}{b^3}$$

where R_f was the bending stress, F was the breaking load, b was the width of the sample, and l was the distance between the ends of the support.

- *Simple compression test*

The half-prisms of the sample obtained after fracture in bending was broken in compression as indicated in Figure 16. The breaking stress was calculated by:

$$R_c = \frac{Fc}{b^2}$$

where R_c was compressive stress, Fc was the breaking load, and b was the width of the sample.

The results obtained for each of the 6 half-prisms were rounded to the nearest 0.1 MPa and were taken as an average. If one of the 6 results differed by ±10% from this average, it was discarded, and the average was then calculated from the 5 remaining results. If again one of the 5 results deviates by ±10% from this new average, the series of 6 measurements was discarded. In that case, the reasons for this dispersion were investigated: problems in mixing and/or implementation and/or conservation.

Minimum saturation strength and maximum dry strength

The so-called maximum dry resistance for the powder of Bridelia is the strength measured when the specimens were dried. This was obtained after a stay in the oven until the content of water was constant. The so-called minimum saturation resistance is the resistance measured when the specimens were saturated. This was obtained after a stay in water until saturation.

Weather resistance test

The aim of this test was to assess the behavior of the tri-layer coating applied to a real wall exposed to bad weather. To do this, an experimental gable wall of

1.5 m long and high was built with bricks measuring 29.5 cm × 14 cm × 9.5 cm in soil stabilized with cement and was exposed to bad weather (sun, rain, wind, etc.). The wall was divided into two parts. The tri-layer coating was applied to one of the parts of the wall and a non-stabilized mortar of soil was applied to the other part. The behavior of the two surfaces was observed. Figures 17-21 show the process of application of the tri-layer coating.

Figure 17. Application of the bonding layer.

Figure 18. Preparation of the body of the coating.

Figure 19. Application of the body of the coating.

Figure 20. Wall after application of the body of the coating.

Figure 21. Wall after application of the protective layer.

4. Results and Discussions

4.1. Result of the Characterization of the Soil

The analysis of the particle size of the soil used provided the results in Table 1. The graph in Figure 22 represents the curve of the particle size of this soil. The limits of Atterberg provide a limit of liquidity of 34%, a limit of plasticity of 16%, and an index of plasticity of 18%. The test of blue of methylene gives a value of 2.3. According to the French soils classification for earthworks, so-called GTR classification, it is a soil of class B6. The HRB (Highway Research Board) classification confirms this: soil of class $A_{2\text{-}6}$. It is therefore a clayey sand of average plasticity.

4.2. Results of Compression and Bending Tests

The results of mechanical tests carried out on the samples, with and without addition of the powder of Bridelia, at saturated state and dry state, are presented in Figure 23 and Figure 24.

Table 1. Result of the sieving of the soil.

Diameter (mm)	5	2.5	1.25	1	0.8	0.63	0.5	0.315	0.25	0.125	0.08	0.063
Passants (%)	100	95	67	43	38	35	29	25	23	19	17	15

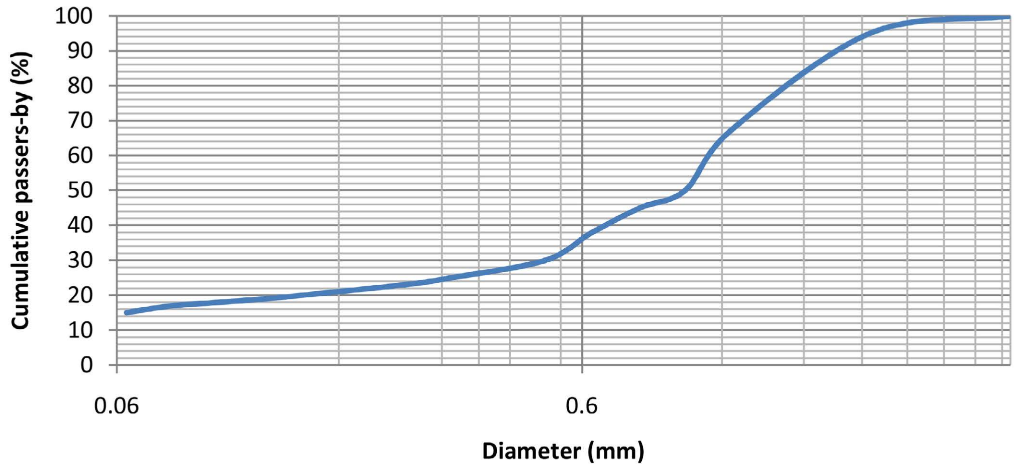

Figure 22. Curve of the particle size of the soil studied.

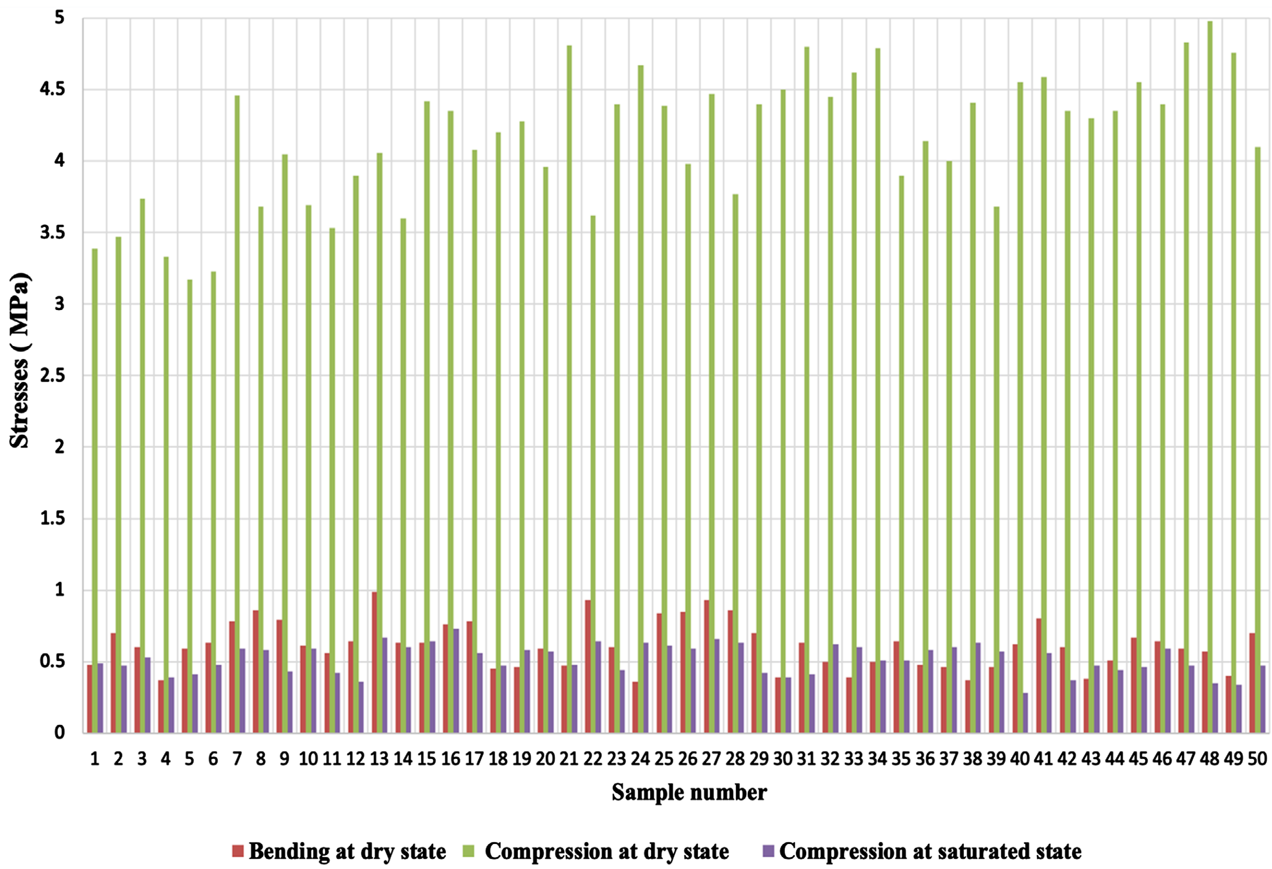

Figure 23. Results of the compression and bending tests on the material with addition of powder of Bridelia.

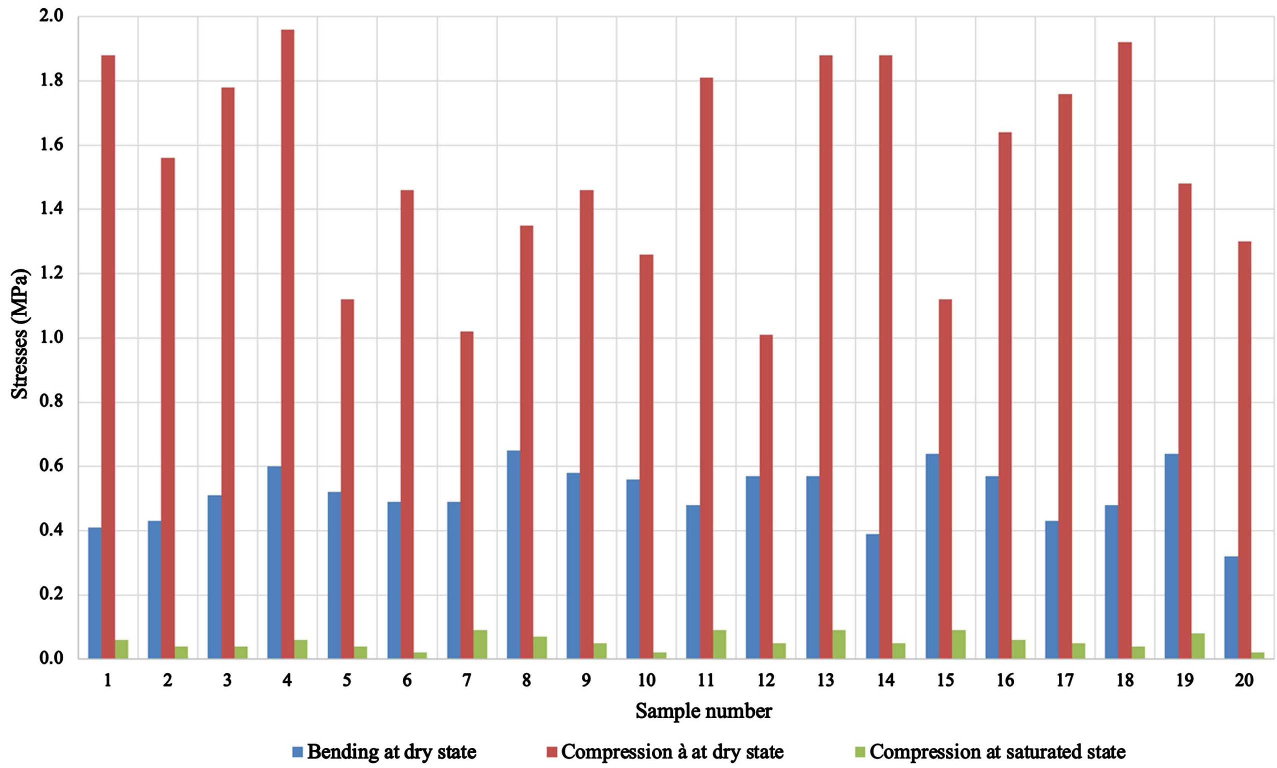

Figure 24. Results of the compression and bending tests on the raw material (without addition of powder of Bridelia).

4.3. Results Analysis

4.3.1. Analysis of Results on Material in the Dry State

The compressive stresses on the composite material (soil + powder of Bridelia), at dry state, vary from 3.17 MPa to 4.98 MPa. On the raw material (without the addition of powder of Bridelia), the compressive stresses obtained under the same conditions, at dry state, vary from 1.01 MPa to 1.96 MPa; it appears that the addition of the powder of Bridelia increases the resistance between 154.08% and 213.86%.

The values of the bending strength are low, ranging from a minimum of 0.37 MPa to a maximum value of 0.93 MPa, at dry state, for the composite material. For the raw material, the values of the bending strength are from 0.32 MPa to 0.65 MPa. The increase in bending strength by adding the powder of Bridelia is low from 15.62% to 43.07%. Even stabilized with the powder of Bridelia, the bending strength is low. It is therefore not desirable to use the composite material in bending situations.

4.3.2. Analysis of Results on Material in the Saturated State

At saturated state, the compressive stresses on the composite material vary from 0.2 MPa to 0.67 MPa, while on the raw material, the compressive stresses obtained under the same conditions are almost zero 0.02 MPa, to 0.09 MPa; it appears that powder of Bridelia makes the composite material more water-repellent. As for the bending stresses, at the saturated state, they are zero.

4.3.3. Weather Resistance Test Result

After four years, corresponding to four (4) cycles of rainy and dry seasons, observation of the witness wall shows that the part made of non-stabilized coating has suffered strong erosion while the part made of stabilized coating has remained intact. The three-layer coating in the composite material resists to bad weather better than the traditional raw soil coating.

5. Conclusion

The aim of this study was to create a composite material capable of providing a solution to the problem of earthworks. The material created is the tri-layer earth-powder coating from Bridelia. It is a composite material applied in three layers (the adhesion layer, the coating body, the protective layer) and composed of three elements (soil, water, powder from the stem bark of Bridelia and its derivatives. The body of tri-layer coating made of soil stabilized with the powder of Bridelia is dependent on the action of water. To attenuate the effect of water, it is necessary to protect the body of coating by a coating made of a concentrated solution of hydrolysable tannin.

In the most unfavorable case, for example, when the structure is immersed in water, the most unfavorable possible stress of the coating body of the order of 0.3 MPa was recorded.

The highest stresses were obtained when the composite material was in the dry state with values which can reach 4.38 MPa and the coating can be classified in category CSIII of the classification of hardened mortars of the French standard NF-EN 998-1 [19].

Conflicts of Interest

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

References

[1] INS Cameroun (2022) Conditions de vie des populations et profil de pauvreté au Cameroun en 2001.

[2] Pierre, J.-S. (2009) Echantillonnage. UMR 6553.

[3] Box, G.E.P., Hunter, W.G. and Hunter, J.S. (1978) Statistics for Experimenters. John Wiley & Sons, New York.

[4] Finney, D.J. (1975) An Introduction to the Theory of Experimental Design. University of Chicago Press, 235.

[5] CEA (1978) Statistique appliquée à l'exploitation des mesures. Masson, Paris.

[6] Banakinao, S. (2016) Characterization and Modeling of the Mechanical Behavior of Heterogeneous Microstructures: Case of the Composite Material Soil Pod of Néré and Its Applications in Civil Constructions. PhD Thesis, University of Lomé, Lomé.

[7] Banakinao, S., Drovou, S. and Attipou, K. (2022) Influence of Cement Dose on the Durability of Structures in Stabilized Compressed Earth Blocks. *International Journal of Sustainable Construction Engineering and Technology*, **13**, 121-129.

https://doi.org/10.30880/ijscet.2022.13.01.011

[8] NF P 11-300 (1992) Exécution des terrassements—Classification des matériaux utilisables dans la construction des remblais et des couches de forme d'infrastructures routières.

[9] NF P 94-054 (1991) Détermination de la masse volumique des particules solides: méthode du pycnomètre à eau. Homologuée Octobre 1991.

[10] NF P 94-056 (1996) Analyse granulométrique par tamisage à sec après lavage. Homologuée Mars 1996.

[11] NF P 94-057 (1992) Analyse granulométrique : méthode par sédimentation. Homologuée Mai 1992.

[12] NF P 94-052-1 (1995) Détermination de la limite de liquidité au cône de pénétration. Homologuée Novembre 1995.

[13] NF P 94-051 (1993) Détermination de la limite de liquidité à la coupelle, limite de plasticité au rouleau. Homologuée Mars 1993.

[14] Banakinao, S., Tiem, S., Attipou, K., Novinyo, K., Lolo, K., Koutsawa, Y., and Bedja, K.-S. (2017) Use of the Nere Pod (*Parkia Biglobosa*) for the Improvement of Mechanical Properties of Soils. *American Journal of Applied Sciences*, **14**, 302-308. https://doi.org/10.3844/ajassp.2017.302.308

[15] Banakinao, S., Sonnou, T., Attipou, K. and Lolo, K. (2020) Shear Resistance of Soils Improved with Tannins of Néré Pod. In: Adjallah, K., Birregah, B., Abanda, H., Eds., *ICEASSM* 2017: *Data-Driven Modeling for Sustainable Engineering*, Vol. 72, Springer, Cham. https://doi.org/10.1007/978-3-030-13697-0_20

[16] Samah, O.-D., Banakinao, S., Lolo, K. and Attipou, K. (2022) Development of Roofing Tiles Support Made from Bituminous Plywood. *American Journal of Applied Sciences*, **19**, 99-104. https://doi.org/10.3844/ajassp.2022.99.104

[17] Drovou, S., Pizzi, A., Lacoste, C., Zhang, J., Abdulla, S. and El-Marzouki, F.M. (2015) Flavonoid Tannins Linked to Long Carbohydrate Chains-MALDI-TOF Analysis of the Tannin Extract of the African Locust Bean Shells. *Industrial Crops and Products*, **67**, 25-32. https://doi.org/10.1016/j.indcrop.2015.01.004

[18] NF P18-411 (1981) Définitions et spécifications des mortiers pour maçonnerie—Partie 1 : mortiers d'enduits minéraux extérieurs et intérieurs.

[19] NF-EN 998-1 (2016) Definitions and Specifications of Mortars for Masonry—Part 1: Exterior and Interior Mineral Coating Mortars.