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## A Natural Material for Sustainable Infrastructure in Pobe: Case of Palm Fibres

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### Abstract

Clay soils, due to the presence of swelling minerals, are prone to shrink-swell. Soil stabilisation is commonly used to reduce this risk, especially for light, shallow constructions. In Benin, palm branches are often discarded, polluting the environment. This study examines the impact of palm fibers on the geo-mechanical properties of the soil in Igana commune in Pobè. Physical and mechanical tests were carried out. The physical tests classify this soil as A-7-5 according to the HRB classification: a clayey soil, of the very plastic, non-organic, non-inactive silt type, with a high swelling potential and a high plasticity index. The mechanical tests revealed that adding 0.30% fiber increased the compressive strength at 7 days, reaching 0.025 MPa, confirmed by the flexural test with the same fibre content. As for the other mechanical tests, we obtained a maximum value of 1.63 for 95% raw clay in the CBR test and a maximum cohesion at 0.15% palm fiber in the shear test.

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### Keywords

swelling minerals, soil stabilisation, geo-mechanics, fiber content.

### Introduction

Clay soils pose major challenges in the field of civil engineering, causing significant damage to structures, particularly in semi-arid regions such as Benin. Every year, these soils cause significant damage to buildings, and the extent of the damage depends mainly on fluctuations in the water content beneath the foundations and their rigidity.

Expansive clays, in particular, change volume in response to changes in humidity. Previous studies have focused on understanding the behaviour of expansive clays and how parameters affect swelling, as well as the

damage and problems that may occur as a result of volume change.

To date, there have been few studies in the field of soil mechanics concerning the behaviour of clays subjected to high stresses. This field has mainly concerned rocks and powdered materials. In the case of clays, research has focused on the range of pressures common to most civil engineering structures, which generally do not exceed 1 MPa. The option of storing radioactive waste in structures dug into deep clay formations required tests to be carried out in order to understand the behaviour of these materials under the conditions in which they are used, which are characterised, among other things, by

high compaction pressures, contact with a heat source and a change in water status.

The experimental work carried out to describe the behaviour of highly compacted clays includes drained on a plastic clay (Boom) and a stiff clay (Couy), cyclic oedometer tests and monotonic and cyclic triaxial tests on Boom clay, oedometer and triaxial tests on MX80 bentonite, as well as undrained and drained triaxial tests at constant mean pressure and at different temperatures on reworked samples made from a mixture of sand and bentonite. Soil movements typically occur during a rainy period following a dry period or, conversely, during a dry period following a rainy season. Vegetation in the immediate vicinity of structures is also a known parameter that contributes to increasing the amplitudes of water variation in the soil beneath the structures, particularly during periods of drought. Lack of drainage, or inadequate drainage, is another factor that contributes to these movements, particularly during rainy seasons.

However, although the use of plant fibres is not new, the Egyptians are said to have used natural fibre composites around 3,000 years ago. The current trend towards exploiting and using available and sustainable natural materials is being strongly encouraged in various industrial sectors.

There are a number of reasons for this, since these eco-materials have a number of advantages, such as their availability at low cost on the one hand, and their mechanical and thermal performance and low weight on the other.

Recent studies have shown that incorporating natural fibres reduces the size of shrinkage cracks, improves durability and tensile strength, and even reduces the thermal conductivity of composite materials.

In addition, the use of plant fibres in soil stabilisation can reduce waste and emissions by emissions by 42% compared with the use of traditional stabilisation materials such as cement.

Palm fibre has been one of the favourable materials used in stabilisation and geotechnical engineering projects in recent years due to its durability, lack of damage to the environment, biodegradability, availability and cost-effectiveness in the context of the widespread worldwide call for a return to nature and the protection of the earth our property.

Palm waste fibres are only used in traditional ways. For example, it is used in the craft industry (to make hats,

baskets, carpets, etc.) and in the construction industry (house frames).

Pobè and the surrounding area are often rich in natural resources, including palm trees.

In order to exploit the full potential of palm fibres in the construction industry, in-depth research into their properties is required. The aim of this research is to identify optimum fibre production and processing methods, particularly suited to modern construction applications.

Previous research has shown that incorporating plant fibres enhances the physical and mechanical properties of clay soils. However, these findings are generally based on the use of hydraulic or mineral binders combined with plant fibres. The use of certain binders does not correspond to current practices in certain regions of developing countries, so the question arises: would it be possible to obtain similar results using only swelling clay and palm fibres? In addition, could the improvement of these soils with palm fibres be sufficient for use in the design of infrastructure in Pobè? In this context, a study on the influence of the geo-mechanical characteristics of clay soils stabilised with palm fibres is necessary. The subject of the study is thus: "the use of palm fibres to improve the resistance of infrastructures in areas with swelling soils in Pobe".

## **Materials and Methods**

### **Presentation of the study environment**

Igana is an arrondissement in the Plateau department of Benin. It is an administrative division under the jurisdiction of the commune of Pobè. According to the population census carried out by the Institut National de la Statistique Bénin in 2013, Igana has 1,848 inhabitants with a male population of 5,585 and 6,263 women with a household population of 1,946. It covers an area of 72.798 square kilometres. lies between 7°1'30" and 7°6'0" north latitude and 2°40'30" and 2°46'30" east longitude. It is bordered to the north by the Towè district, to the south by the Ahoyèyè district, to the east by the Federal Republic of Nigeria and to the west by the Issaba district. The arrondissement of Igana is made up of 23 localities, including :TgboIwadjo, Igboroko, IganaIIè, Assagalkpakoto, AbiléAbèdè, Ikpangnikpan, Ihoro, Odjigbon, Igana, Akpaman, Abèkpè Alaga, Eguelou, Kodjèfo, Igbo Odou, Kadjola, Agbélé, Igbo Oko, Igno Ito, Aguido, Ogouba, Oko Ilakpo, Illèmon. It has a

surface area of 400 km<sup>2</sup>, representing 11% of the area of the department and 0.46% of that of Benin. It is located in a median depression that crosses the whole of Benin from west to east, at the northern end of the Plateau department.

### **Experimental programme**

The general objective of this work is to determine the influence of the geo-mechanical characteristics of the Igana clay soil stabilised by palm fibres. The behaviour of clay soils is often problematic, and the use of natural fibres to improve these soils has already been implemented in several previous studies. To carry out this study, it is essential to identify the clay. This identification requires knowledge of its physical properties, such as the elements making up the soil, its physical characteristics (water content, density, etc.) and its granulometric characteristics. Hence the physical tests that are carried out.

Before the analyses, the samples were dried in an oven. To study the distribution of the different grains in our sample, particle size analysis (by wet sieving and sedimentometry) was carried out in accordance with standards NF P18-560 (1978) and NF P94-057 (1992) respectively. The liquidity limit was determined using the Casagrande disc method and the plasticity limit using the roller method. These Atterberg limits were determined in accordance with standard NF P94-051 (1993). The optimum moisture content and maximum dry density were determined by the normal Proctor test in accordance with standard NF P94-093 (1999). The optimum water content is an index that characterises the behaviour of a clay soil in the presence of water. The organic matter content of the soil was determined in accordance with standard NF P 94-047. This determination was carried out using hydrogen peroxide.

Following the physical tests, mechanical tests were carried out to study the behaviour of the clay and the mixture: the settlement of the clay (intact) under the effect of a given force, its coherence, its strength, etc.). The odometer test was carried out in accordance with standard XP P4 P94-090-0001 to express the settlement of intact clay under the effect of a mass. Proctor tests were then carried out in accordance with French standard NF P 94-093 to determine the optimum moisture content. The direct shear test and the CBR test were used to understand the impact of the palm fibre reinforcement on the shear strength of the soil. These different tests were

carried out on all the mixes with different levels of palm fibre. The simple compression test, introduced for the first time by FENZY (1957), was carried out on 20 specimens in accordance with standard

NF EN 13286-41 on cylindrical specimens measuring Ø5 mm × H10 mm to determine the nominal compressive strength of the cylindrical specimens. Finally, a three-point bending test was carried out on 12 prismatic specimens measuring 16 x 4 x 4 cm<sup>3</sup> in accordance with the standard (NBN EN 1015-11) to study bending behaviour.

As for the composition of the mixes studied, the fibre contents (0.00%, 0.15%, 0.3% and 0.45%) were chosen on the basis of previous studies carried out by 19. The palm fibre and clay were mixed manually, depending on the fibre content. This treatment method, which is very common in soil stabilisation techniques, involves mixing the clay with the palm fibre before compaction. The clay + water materials are first mixed manually. The mixes were left to homogenise for 5 minutes. Finally, the fibres were added by hand. The material was then placed and compacted immediately after mixing. For each mix, 2 kg of clay were taken.

The quantity of water added is that which favours the workability required to prepare the test specimens. The specimens were made to a compactness close to the modified Proctor optimum and with different water contents, i.e. 17.90%, 18.20%, 19.40% and 20.10%. A prismatic mould measuring 16 x 4 x 4 cm<sup>3</sup> was used for triaxial bending and compression (NF EN 13286-41). The prismatic moulds are filled in two layers. The specimens were then stored in the laboratory at room temperature for 7 days following the crushing days.

The materials studied were swelling Pobe clay and palm fibers.

### **Clay soil**

The clayey raw materials that are the subject of the study were taken at Igana at a depth of between 1.50 m and 1.80 m, with the following coordinates: latitude 7° 1'9.7572" North and longitude 2° 42'16.06572" East.

### **Mixing water**

The water used comes from the Société Nationale des Eaux du Bénin (SONEB).

**Table.1** Sampling site

Locality	Geographical Coordinates		Draining Depth(M)
	Longitude	Latitude	
IGANA	2° 42'16.06572"E	7° 1'16.06572"NORTH	-0.80 -1,00 -2,00

**Table.2** Cohesion value and angle of friction as a function of fibre content

Materials	C(KPa)	$\phi(^{\circ})$
Raw clay	44,8	3,01
Clay +0.15% fibre	93,4	21,3
Clay +0.30% fibre	79,9	11,9
Clay +0.45% fibre	75,9	16,5

**Figure.1** Study site

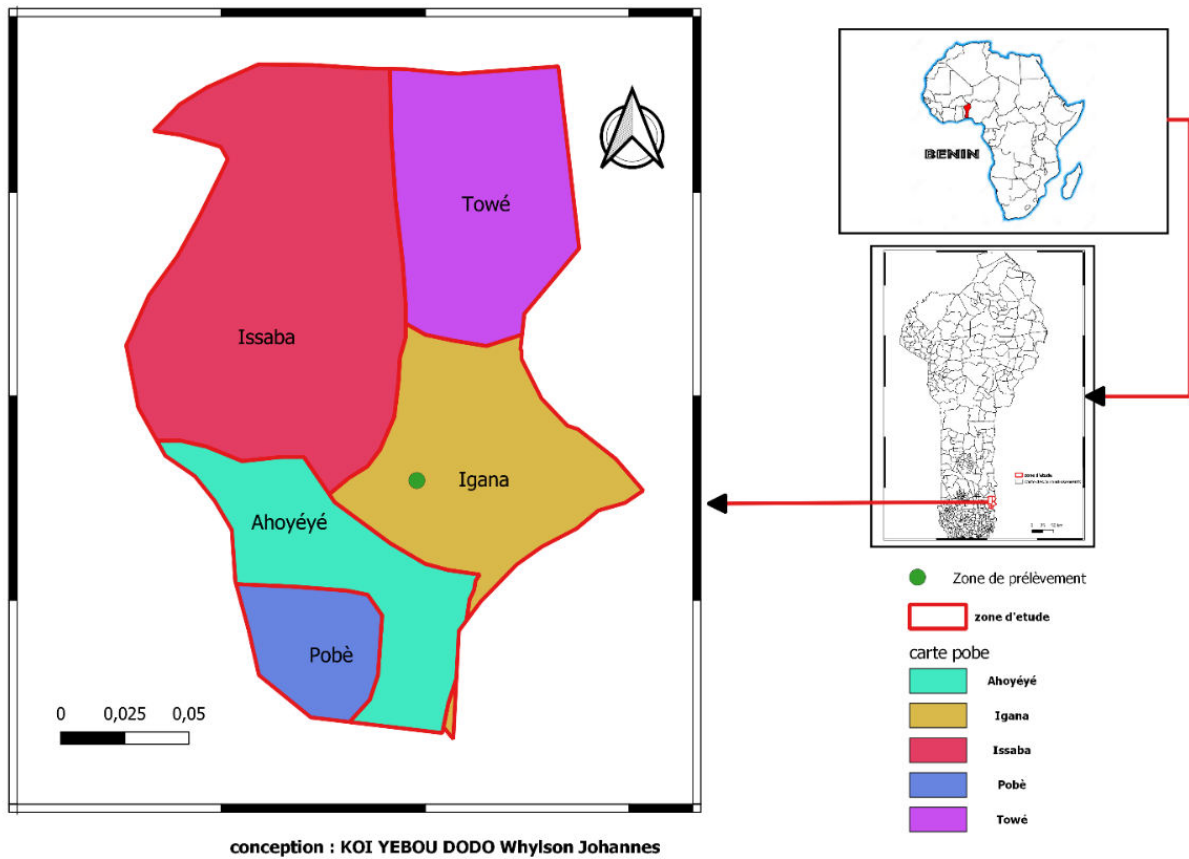


Figure.2 Palm fibre extraction process



Figure.3 Palm fibers extraction process



Figure.4 Different levels of palm fibers incorporated into clay

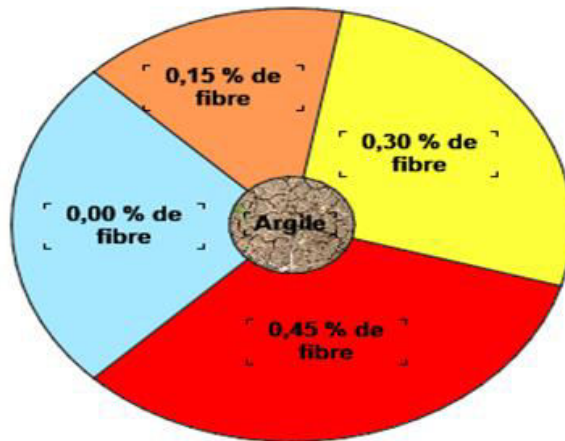


Figure.5 Mixture of clay and palm fiber with different contents (0, 15%, 0, 30%, 0, 45%)



Figure.6 Schematic and representative view of the prismatic mould (4 x 16 x 4 cm<sup>3</sup>)

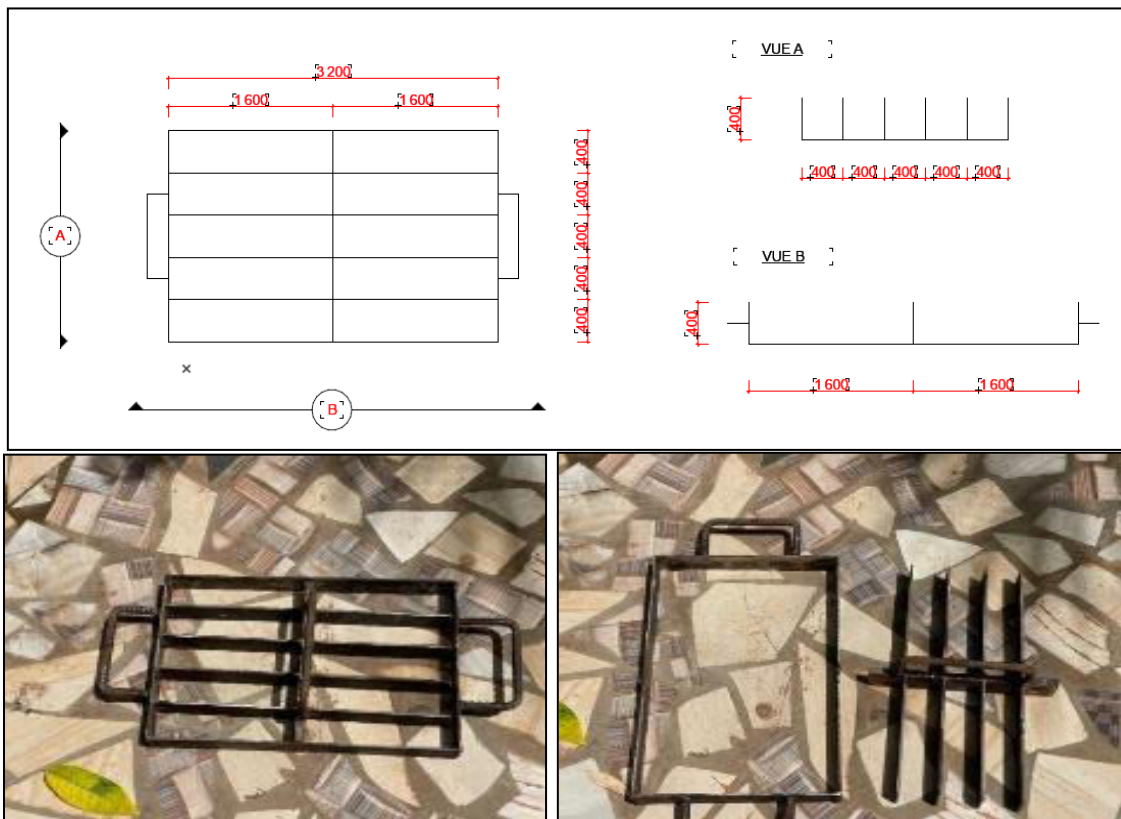


Figure.7 4 x 16 x 4cm<sup>3</sup> Briquette samples



Figure.8 Casagrande chart

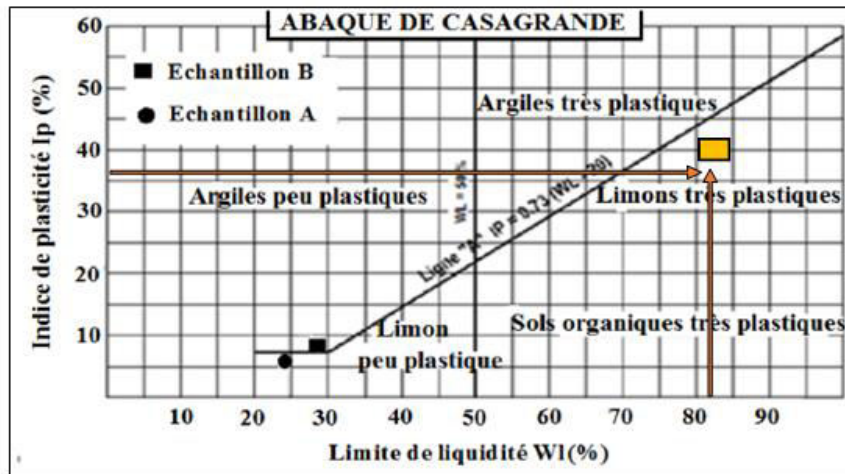
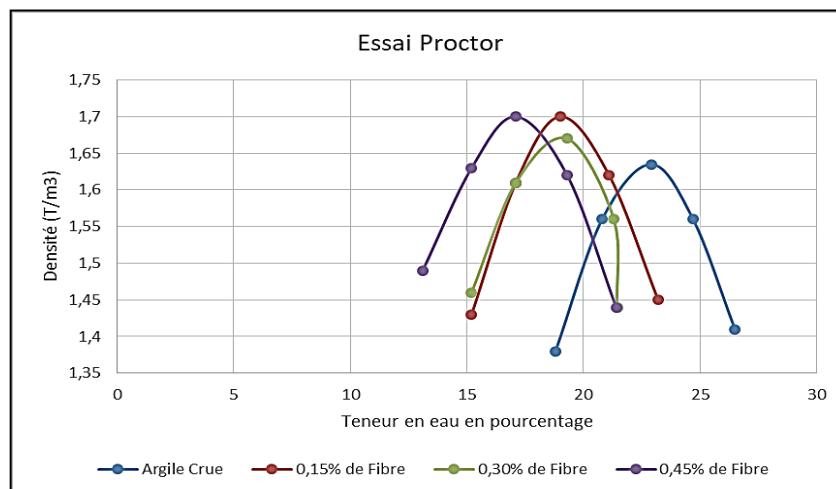
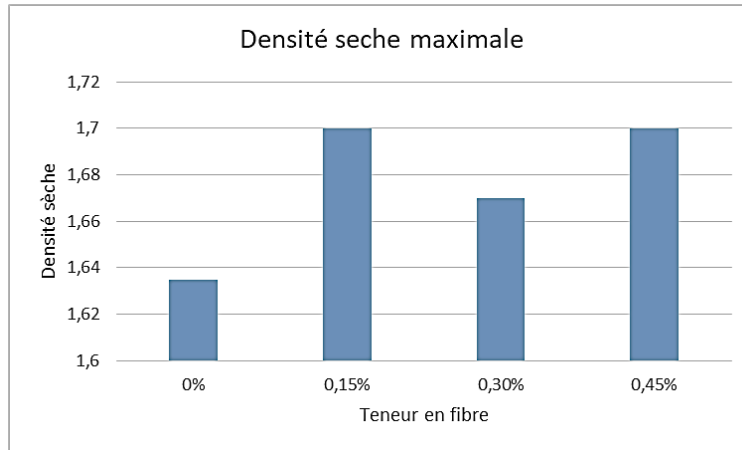


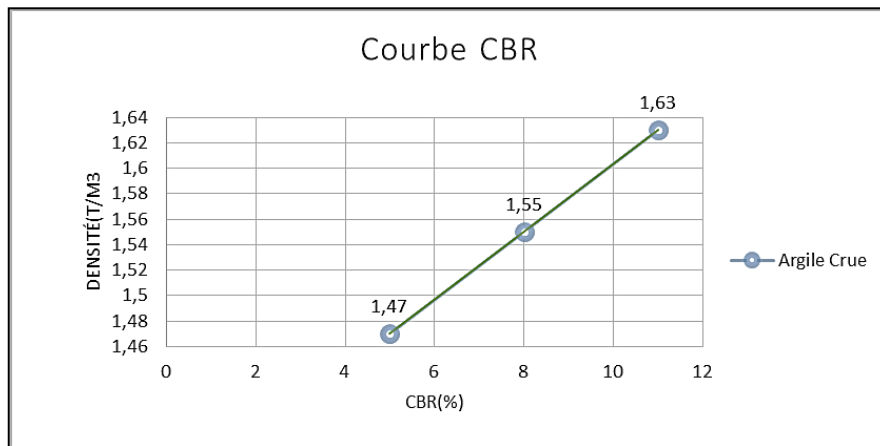
Figure.9 Density as a function water content



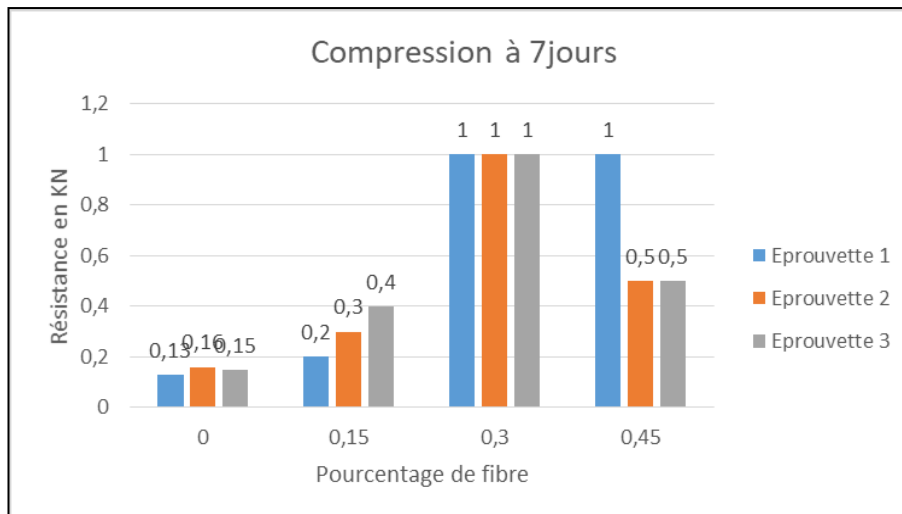
**Figure.10** Maximum dry density as a function fiber content



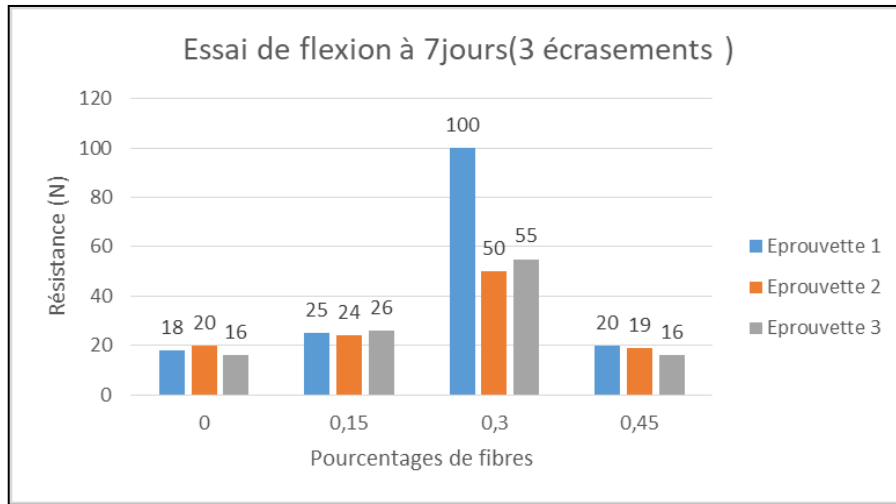
**Figure.11** Density as a function of CBR



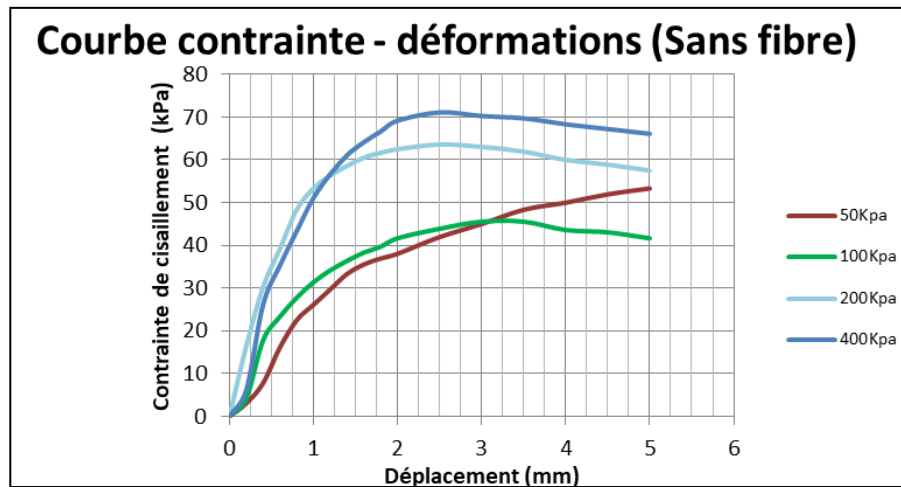
**Figure.12** Compressive strength as a function of fiber percentage



**Figure.13** Flexural strength as a function of fiber percentage



**Figure.14** Shear strength curve for unbaked clay



**Figure.15** Shear strength curve for unbaked clay+0.15 fiber

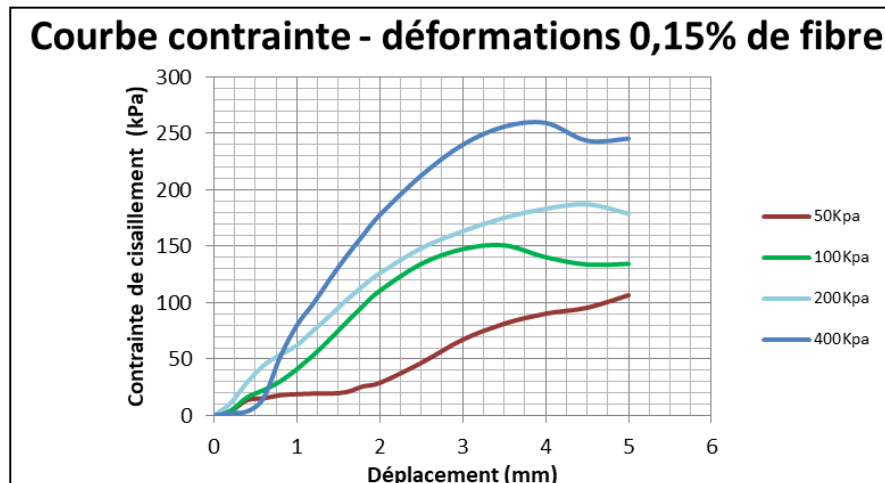


Figure.16 Shear strength curve for unbaked clay+0.30 fiber

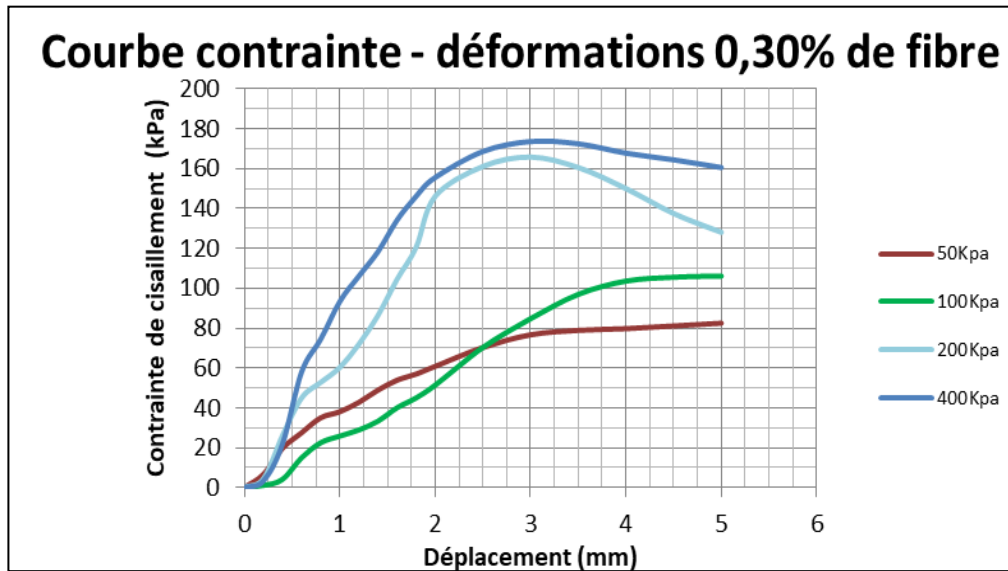
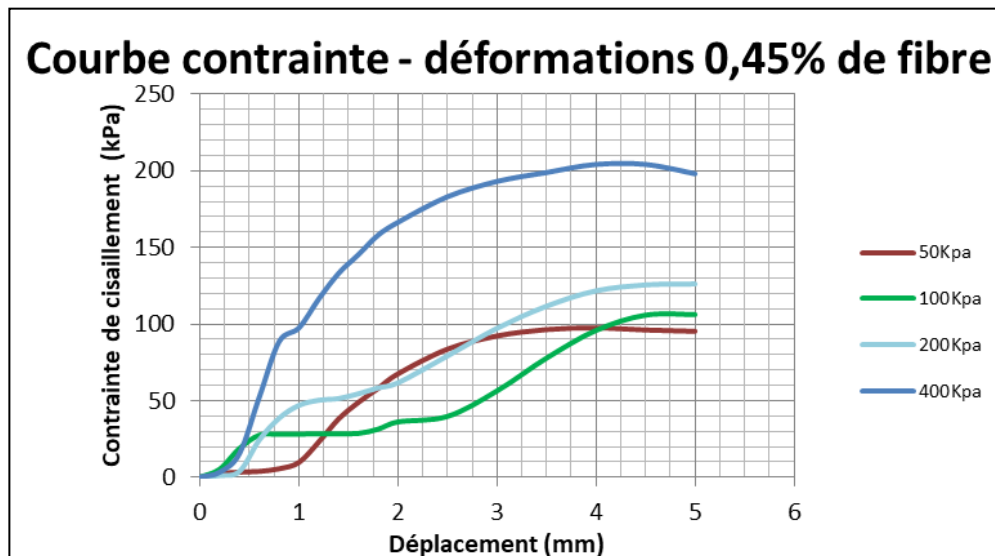


Figure.17 Shear strength curve for unbaked clay+0.45fiber



**Fibers**

We chose palm trees in the IGANA area. Every year, they produce a very large quantity of by-product in the form of abandoned waste. Palm is the most available by-product of palm trees. The aim of this work is therefore to contribute to the use of the fibres extracted from the palm.

The material was then placed and compacted immediately after mixing. The amount of water added was that which favoured the workability required to

prepare the specimens. The specimens were produced with a compactness close to the modified Proctor optimum and with different water contents, i.e. 17.90%, 18.20%, 19.40% and 20.10%. Two types of specimen were produced: the first was prismatic in shape with dimensions of 16 x 4 x 4 cm<sup>3</sup> and the second was cylindrical with a diameter of 50 mm and a height of 100 mm.

Prismatic moulds were filled in two layers, while cylindrical moulds were filled in three layers. The samples were then stored in the laboratory at room

temperature for 7, 14 or 28 days, depending on the number of days of grinding.

## Results and Discussion

### Physical characterisation tests

#### Particle size analysis

The grain size distribution of the clay in the commune of Pobè, more precisely in the locality of Igana, was determined by granulometric analysis by sieving and sedimentometry. Figure 3-5 below shows the granulometric curve, which provides indicative values for the granularity of the clay.

#### Casagrande classification

The Casagrande abacus was used to determine the nature of the samples studied.

According to Casagrande's classification, the soil studied is a very plastic silt.

### Mechanical tests on the composite material

The mechanical tests carried out are :

- Standardised Proctor
- The C.B.R
- Simple compression
- Three-point bending
- Direct shear

#### The Proctor test

It can be clearly seen that the addition of fibre increases the maximum dry density of the raw clay, which is  $1.635 \text{ T/m}^3$ . The maximum dry density of  $1.70 \text{ T/m}^3$  is obtained with 0.15% and 0.45% fibre. On the other hand, with 0.30% fibre we observe a decrease in the maximum dry density, which is  $1.67 \text{ T/m}^3$

#### Maximum dry density

It was found that the blend with the highest maximum density and lowest optimum moisture content was the one containing 0.45% fiber.

#### CBR test

From this test the CBR index at 100% is equal to 11 and the CBR index at 95% is equal to 8.

### Compression test

From this test we conclude that the composite material clay + palm fibre offers greater compressive strength at 0.30% fibre for the three specimens produced.

### 3-point bending test

In the triaxial bending test, the clay + palm fibre composite offers greater bending strength at 0.30% fibre.

### Shear test

The following curves show the shear strengths of the clay at different contents corresponding to stresses of 50 KPa, 100 KPa, 200 KPa and 400 KPa.

According to the shear curve, the maximum stress is 65.76 Kpa, obtained by the normal stress corresponding to the last step  $\sigma_n = 400 \text{ Kpa}$ . Furthermore, the lowest stress is that of the 50 Kpa normal stress, which is 47.42 Kpa.

According to the shear curve, the maximum stress is 249.35 Kpa, obtained by the normal stress corresponding to the last step  $\sigma_n = 400 \text{ Kpa}$ . Furthermore, the lowest stress is that of the 50 Kpa normal stress, which is 112.89 Kpa.

According to the shear curve, the maximum stress is 169.19 Kpa, obtained by the normal stress corresponding to the last step  $\sigma_n = 400 \text{ Kpa}$ . Furthermore, the lowest stress is that of the 50 Kpa normal stress, which is 90.44 Kpa

According to the shear curve, the maximum stress is 194.39 Kpa, obtained by the normal stress corresponding to the last step  $\sigma_n = 400 \text{ Kpa}$ . Furthermore, the lowest stress is that of the 50 Kpa normal stress, which is 90.71 Kpa. It can be seen that the addition of fibres to the clay increases the shear stress, whatever the content. The highest shear stress was obtained with 0.5% fibre content.

### Cohesion and angle of friction

Table 2 shows the results for the cohesion and angle of friction of the different mixes.

Table 2 shows that the maximum cohesion value of 93.4 KPa is obtained with a fibre content of 0.15%, which corresponds to the highest angle of friction of  $21.3^\circ$ .

## Conclusion

Our study focuses on the various stabilisation techniques and previous research on fibres. Next, physical tests were carried out on the base soil, revealing that it is a highly plastic illite-type clay-loam soil, inactive and inorganic, with a high degree of plasticity and swelling potential.

Secondly, mechanical tests on different blends (with proportions of 0 to 0.45% palm fibre) showed that, whatever the fibre content, an angle of friction exists. However, the highest cohesion was obtained with a fibre content of 0.15%, giving a value of 93.4 kPa. With regard to compressive strength, the results indicate an optimum palm fibre content of 0.30% for both compression and bending, with respective maximum stresses of 0.025MPa for bending and 0.025MPa for compression. Moreover, to obtain good shear strength, the random direction of the fibres is the best.

In summary, the addition of palm fibres leads to an improvement in the physical and mechanical properties of soils. However, this opens up a number of prospects, including the study of the effect of palm fibre length and direction in mixtures, the impact of pre-treating the fibres before incorporating them into the clay soil, and an in-depth study of the mineralogical composition of Igana clay to justify its use as a composite material.

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