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Экспериментальные исследования

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BORASSUS AETHIOPUM MART OF BENIN USED AS REINFORCEMENT IN CONCRETE: ADHESION CARACTERISATION

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Researches carried out in Benin allowed the use of Borassus aethiopum mart as reinforcement in concrete. The aim of this study is to examine the bond of the two materials. The results of pull out tests have shown that the bonding strength is around 1 MPa. This adhesion rate decreases slightly when the bond length increases; on the other hand, the adhesion rate increases slightly when the concrete strength increases. The behaviour of Borassus / concrete interface shows a first phase of perfect adhesion followed by a second phase of progressive loss of adhesion and a final friction phase which continues until the complete output of the reinforcement from the concrete.

Key words: Borassus aethiopum mart, reinforcement, concrete, pull-out test, bond

1. Introduction

Borassus aethiopum mart is a palm tree which belongs to the *Arecaceae* family. Researches carried out in Bénin showed that this palm tree had been long used during the colonial period. The average land area is 2.1 m² / ha with a minimum of 5.8m² / ha in Savè and 1.9m² / ha with a minimum of 0.1m² / ha and a maximum of 4m² / ha in Ouidah [1]. These low percentages can be explained by the pressure from the local populations on the stands, in particular the felling of the tree for the wine production and for the construction. According to many authors *Borassus aethiopum mart* constitutes in Africa one of the best "timber wood" in the Sahelo-Sudanian zone; Since the arrival of the Europeans, *Borassus aethiopum mart* stands, near the agglomerations have been overexploited for local uses [2-3-4].

Other studies carried out showed that 47.5% of buildings in which *Borassus aethiopum mart* is used are more than 50 years old; 24.9% are between 25 and 50 years old, and 27.6% are over 25 years old in the study area; Buildings more than 50 years old show that the use of *Borassus aethiopum mart* in construction is long dated; the studies carried out on these buildings showed that *Borassus aethiopum mart* structure elements were practically in their original form [5].

In order to optimize *Borassus aethiopum mart* structure elements sections, such as beams, columns etc., [1] interested in physical and mechanical characterization of the ligno-cellulosic material between the pith and bark of this palm tree. So, for 12% of moisture content, the density of ligno-cellulosic material is 890 kg/m^3. This implies that this material belongs to "heavy wood" group [5-6]. But this density is lower than steel density which is 7800 kg/m^3, and higher than Afzélia africana one or Doussié which is 800 Kg / m^3 [7]. The tensile strength is 300 MPa at 12% moisture content. This value is close to steels FeE 215 generally used in reinforced concrete. The compressive strengh is 75 MPa at 12% moisture content. This value is higher than Afzélia africana one wich is 72MPa. The Young modulus in four-point bending at 12% moisture content is 17196 MPa and the failure strength is 186 MPa. These mechanical characteristics of *Borassus aethiopum mart* in the axial direction differ from those reported by [8] which are respectively 105 MPa and 92.5 MPa in tension and compression parallel to the fibers; in compression perpendicular to fibers, the failure strength is 26 MPa.

From all above, this material can be used as reinforcement in the concrete. The four-points bending tests realized by [5] on *Borassus aethiopum mart* reinforced concrete beams showed that the composite material behaves like usual materials. Stress–strain curves presented a first phase of elastic deformation, followed by a second phase of plastic deformation.

However, to our knowledge, there is no research concern the adhesion rate between the two materials. This justifies the present study, which is interested in the determination of the adhesion rate between *Borassus aethiopum mart* and concrete, and the interface behavior of the two materials.

2. Materials and methods

- ***Borassus aethiopum mart***

Borassus aethiopum mart plant (Picture 1) used for this study came from Pahou-Ahozon forest located about 6 km at east of Ouidah and 40 km at west of Cotonou (Bénin) (Figure 1). After felling, these plants were cut, split into slats and conditioned at 12% of moisture content. Then they have been sawn in 20×20 mm² section. The kind of *Borassus* felled is the male.

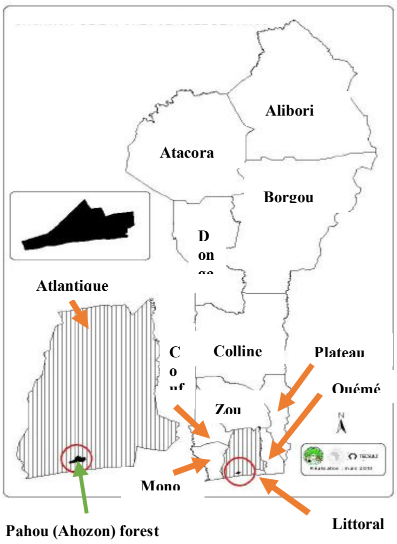
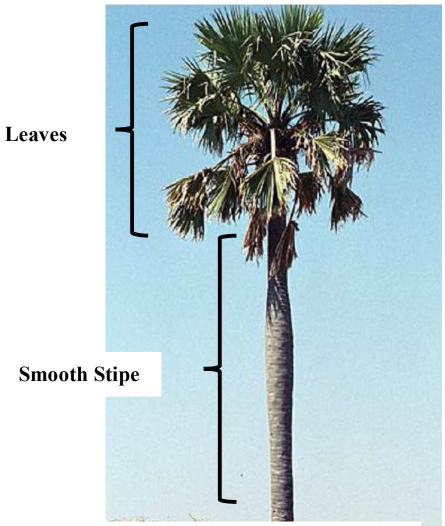


Figure 1. Pahou (Ahozon) forest



Picture 1. Borassus male

Table 1. Specimen's nomenclature

Désignation	Concrete size (mm^3)	Bond length (mm)	Compressive strength of concrete (MPa)	Samples Number
T50-20	100×100×100	50	20	3
T50-30	100×100×100	50	30	3
T80-20	100×100×100	80	20	3
T80-30	100×100×100	80	30	3
T80-20	200×200×200	80	20	3
T'80-30	200×200×200	80	30	3
T150-20	200×200×200	150	20	3
T150-30	200×200×200	150	30	3

- **Concrete**

For this study, we have realized two formulations of concrete by Dreux Gorisse method. Thus, we obtained two compressive strength of concrete such as 20 and 30 MPa. In the first case, the gravel / sand and water/cement ratio is respectively 1.84 and 0.61; in the second case, it's respectively 1.84 and 0.51.

- **Nature of test specimens**

Test specimens elements are ***Borassus aethiopum mart*** with 20×20 mm² cross section embedded respectively in a concrete prism of 200×200×200 mm^3 and 100×100×100 mm^3 size. Table 1 summarizes the nomenclature of the specimens. To avoid the effects of non-uniform shear stress distribution in conventional tests, only the middle part of the bar is subjected to shear [9]. Specimen's configuration is shown in figure 2. In all, 24 test specimens have been realized as shown in picture 2&3.

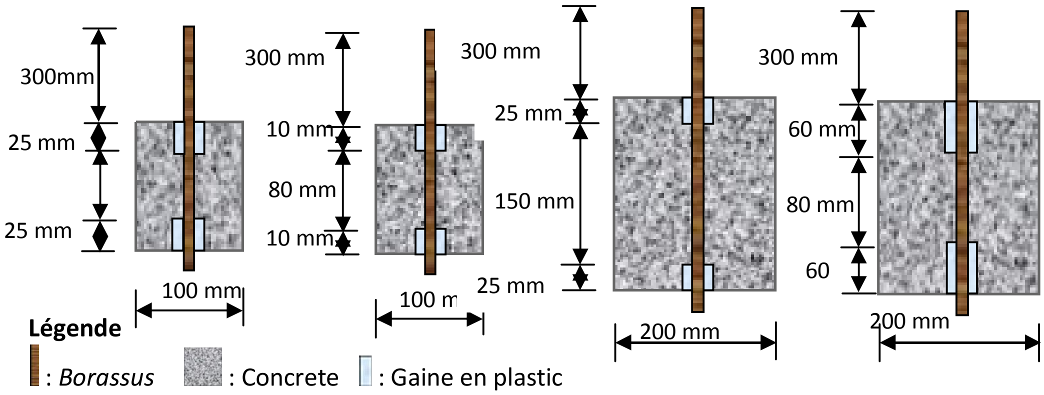


Figure 2. Specimen's configuration

Picture 2. Pull-out specimen with 20 MPa of strengh of concrete

Picture 3. Pull-out specimen with 30 MPa of strengh of concrete

- **Test procedure**

The bonding between *Borassus aethiopum mart* and concrete has been established in pull-out tests shown in figure 3. A good bond between the reinforcement and the concrete is necessary to ensure an effective transfer of tensile stresses from the concrete to the reinforcement [10].

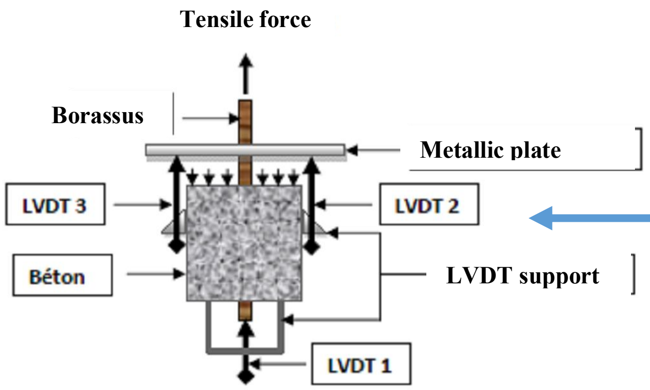
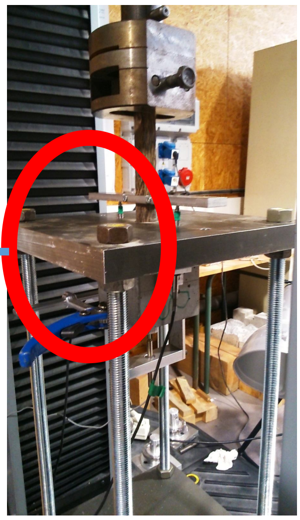


Figure 3. Device detail



Picture: Expérimental device

The experimental device consisted of a MTS press with a maximal capacity of 50 KN and a frame fixed to the test press. The upper jaws of the press hold the specimen through a hole of 30 mm of diameter on the upper plate of the frame. A clamp intimately maintains the contact between the test piece and the plate. Two linear variable displacement transducers (LVDT's) were placed on opposite sides of the test specimen to measure the average slip of *Borassus* relative to concrete. Another LVDT is placed on the bottom of the test specimen to measure *Borassus* displacement as illustrated in picture 5. During the test all datas are recorded in a computer.

3. Results and discussions

Pull-out tests results provided allow us to trace load-deflection curves reflecting the behavior of two materials as shown in figure 4 & 5. Those Figures respectively show the adhesion variation relative to the average displacements of LVDT 2 and 3 for specimen T50-20; T50-30; T80-20; T80-30. In order to differentiate the three samples of the same type of specimen, the designations of the specimens shall be followed by the letters a, b, or c. To better observe the behavior of the interface of the two materials, it is interesting to observe every LVDT displacement. Figure 6 shows the adhesion-displacement curves of the test specimen Tc80-30. In this figure 6, we can observe the displacement at the bottom and at the exit of the embedment. The displacement at the bottom is given by LVDT1 and the displacement at the entrance of the embedment is given by the average of LVDT2 and 3.

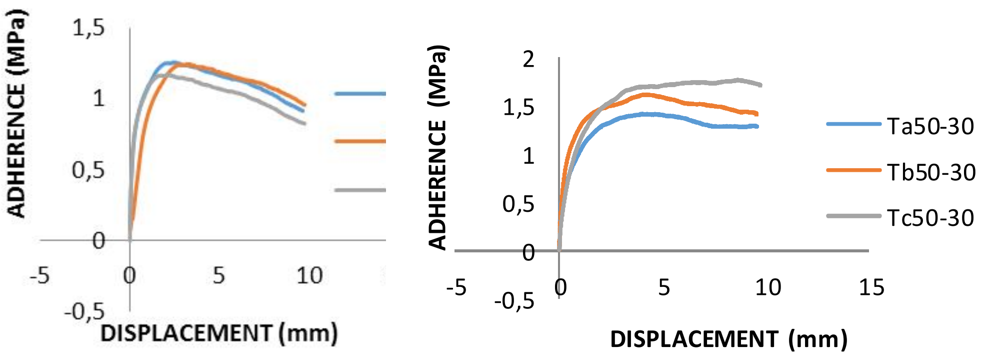


Figure 4. Adhérence - Displacement curves of test specimen T50-20 and T50-30

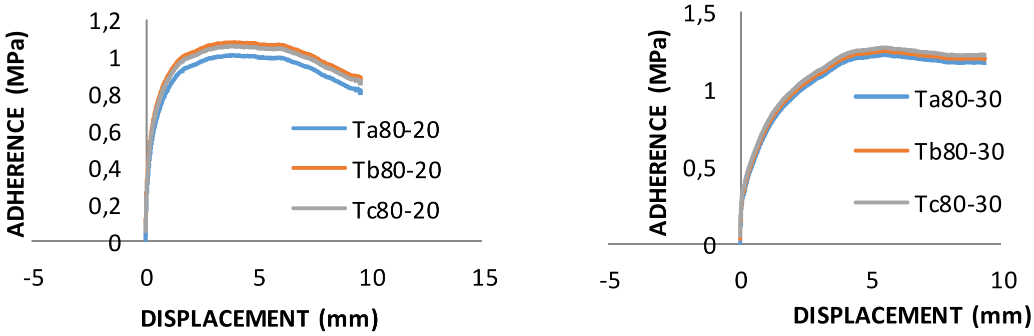


Figure 5. Adhérence - Displacement curves of test specimen T80-20 et T80-30

Close observation of the curves shows a first quasi-linear zone followed by an inflection which continues until the peak of the effort. After the peak, the effort stabilizes at a non-zero residual value. But before the inflection, a first fall occurs, marking the exhaustion of the adhesion. The shape of these curves is close to that reported by some authors after pull-out tests on reinforced concrete specimens [10-11]. For example, in figure 6, we can observe a first phase of perfect adhesion between *Borassus* - concrete; Followed by a second phase of progressive loss of adhesion between the two materials; which results in a gradual increase in strength and a large displacement up to the peak of effort. The last phase is that of friction; it continues until the exit of the reinforcement of the concrete. Picture 6 shows a test piece after testing.

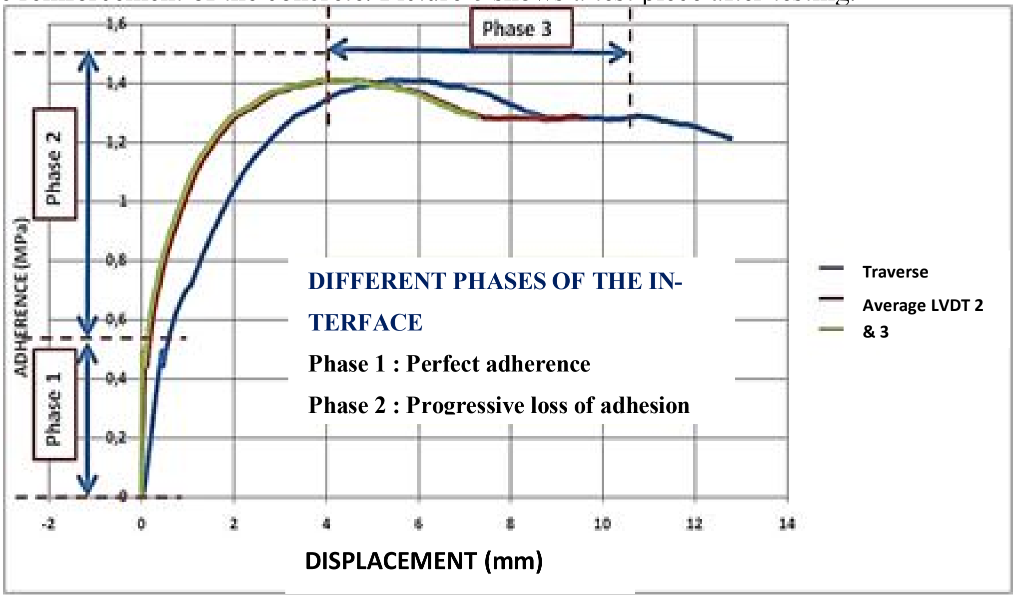
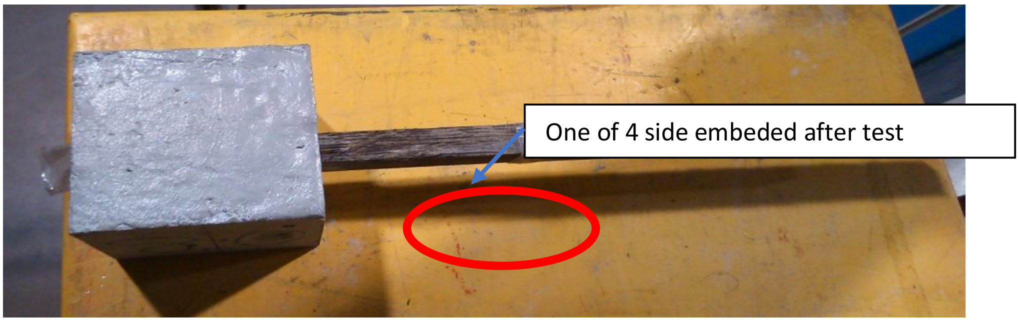


Figure 6. Adhérence-displacement curves for specimen Tc80-30



Picture 5. Specimen after testing

In this picture, we note that the embedment surface remained intact after testing. Some mortar marke visible on this surface testify to the lightness of the bond between the two materials. This phenomenon is noticed with smooth steel and the chemical adhesion constitutes at this stage the unique phenomenon allowing to transfer the forces to bond [12]. Its rupture corresponds to the rupture of the interface.
Moreover, curves analysis and interpretation allowed us to determine the rate of adhesion between the two materials. This rate is given by the following formula:

$$\tau = \frac{F_{max}}{S_{ancrée}}$$

τ: Adhesion stress
F_{max}: Maximal load
$S_{ancrée}$: Surface embeded in the concrete.

In this diagram, we note that for the same embedment length of the reinforcement, the adhesion rate increases slightly with the strength of the concrete. On the other hand, for the same strength of the concrete, the adhesion rate decreases slightly with the embedment length. This same phenomenon was observed after pull-out tests on smooth steel reinforced concrete specimens [12].

Table 2 summarizes the values of the adhesion rate calculated. This table allows us to plot the distribution diagram of adhesion stresses (Figure 7).

Tableau 2. Valeur moyenne du taux d'adhérence

Désignation	Adherence (MPa)	Coefficient of Variation(%)
T50-20	1,3	5
T50-30	1,5	10
T80-20	1	7
T80-30	1,25	2

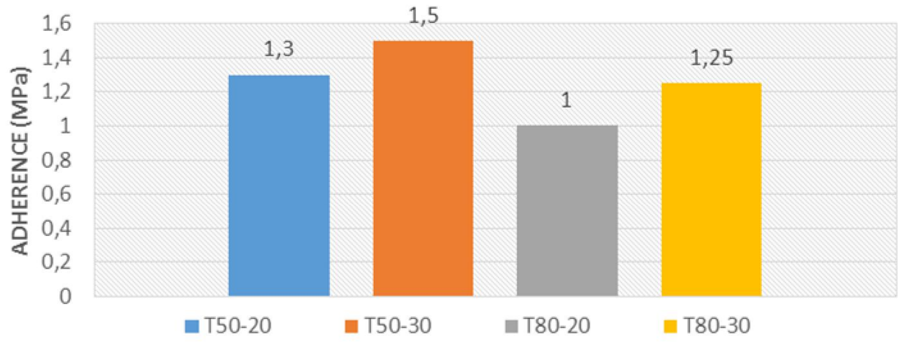


Figure 7. Distribution diagram of adhesion stresses

Moreover, these adhesion values are higher than the bamboo-concrete or rattan-concrete adhesion rate which is around 0.5 MPa [11-13-14].

In the case of the test specimens of 200 mm side, during the tests, we observed ruptures appears at the head of the specimen. This reveals the influence of the confinement on the adhesion between the two materials.

4. Conclusion

In conclusion, this research allowed us to evaluate the adhesion rate between *Borassus* and concrete and to study the behavior of the interface of the two materials. It appears that *Borassus*-concrete adhesion is around 1 MPa; it is equal to smooth steel-concrete adherence, but greater than bamboo-concrete, or rattan-concrete one which is around 0.5 MPa [9-12-13]. The behavior of the interface presents a first phase of perfect adhesion between *Borassus* and concrete; Followed by a second phase of progressive loss of adhesion between the two materials and a last friction phase which continues until the concrete reinforcement is released.

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ВОЛОКНА ПАЛЬМЫ, РАСТУЩЕЙ В БЕНИНЕ, ИСПОЛЬЗУЕМЫЕ КАК АРМАТУРА В БЕТОНЕ: ХАРАКТЕРИСТИКИ СЦЕПЛЕНИЯ

SOHOUNHLOUE A.Y. JAMIK, GBAGUIDI A.G. LEOPOLD, SOLBES B., GALIMARD Ph.

Исследования, выполняемые в Бенине, подтверждают возможность использования волокон пальмы (Borassus aethiopum mart t) в качестве арматуры бетона. Изучение сцепления этих двух материалов есть цель представленного исследования. Результаты, выполненных экспериментов, показали, что сила сцепления составляет порядка 1 МПа. Показатели сцепления слегка понижаются, когда длина сцепления увеличивается, с другой стороны, показатели сцепления слегка увеличиваются, когда прочность бетона увеличивается. Поведение материала из волокон пальмы и бетона показывает, что в начале испытания появляется значительное сцепление, во второй фазе испытания следует прогрессирующее снижение сил сцепления и, наконец, финальная стадия испытания включает в себя выдергивание волокнистой арматуры из бетона.

КЛЮЧЕВЫЕ СЛОВА: Borassus aethiopum mart, армирование, бетон, тест на выдергивание арматуры из бетона, сцепление.

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