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Original Article

Mechanical Characteristics of Kenyan Borassus Aethiopum Mart timber as Reinforcement for Concrete

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Abstract *- The construction industry consumes a significant amount of energy and resources in most countries; research into the partial replacement of non-renewable contemporary building materials with renewable natural materials has risen recently. Several studies have been conducted in Africa to expand the quantity of knowledge available on Borassus Aethiopum Mart timber. It may be utilized as a standalone material or as a reinforcement in cement composites. This research aims to examine the mechanical properties of Borassus Aethiopum Mart timber and the adhesion of the Borassus-concrete interface. The results of tests conducted on the upper and lower parts of the wood of Borassus Aethiopum Mart from Kenya show compressive strengths of 56.551 ± 18.247 MPa and 60.730 ± 12.84 MPa, shear strengths of 7.657 ± 3.009 MPa and 8.131 ± 1.713 MPa, 12.4 kN and 5.41 kN in hardiness for the moisture content of 29.495 ± 6.685% and 21.274 ± 1.647% and a density of 802 ± 101 kg / m^3 and 965 ± 24 kg / m^3. Young's moduli and breaking stresses are 3387.27 MPa and 108.23 MPa for the lower part and 3167.11 MPa and 77.65 MPa for the upper part. The pull-out test results reveal that the adhesion stress at the Borassus-concrete interface is 2.021 MPa.*

Keywords *- Borassus Aethiopum Mart timber, mechanical characteristics, concrete, adhesion.*

I. INTRODUCTION

Borassus Aethiopum Mart, also known as African palm, or Borassus, is a smooth, bottle-shaped palm that can grow up to 25m tall at full maturity. It is named as such because of its crown made up of fan-shaped clusters of leaves. It is a sturdy to massive, single-stemmed evergreen palm with an unbranched stem that can eventually grow to 20-30 meters long by 400-500 mm in diameter, swelling at the base to 850mm, and in the old age to about 50 years also swelled above the midpoint to about 800mm in diameter [1].

Borassus Aethiopum Mart is found in environments where the water table is high in wooded savannah grasslands. It is generally found in sandy soils and floodplains of dense stands, from 0 to 1.200 m; rainfall 900–1400 mm[2]. Itis found in Australia and the African continent, precisely in sub-Saharan Africa in countries like Benin, Burkina Faso, Cameroon, Central Africa, Ivory Coast, Kenya, Madagascar, Malawi, Mali, and so on[3]–[5]; with 70 plants per hectare and 50 plants per hectare in the communes of Save and Ouidah in BENIN[6] and 33-61 trees per hectare in the Abrimasu forest reserve [7].

Different parts of Borassus are used for various needs, namely in the field of food, crafts, medicine, and even in the field of construction[2], [4], [8]–[14]. In construction, this wood provides excellent upright, well-graded pilots for the construction of wharves or piers of bridges and frames[6]–[8], [15], [16]. This wood gives the habitat a relatively long lifespan, and for frames, it is used as a beam, rafters, lintel, and post/ column, but the use of this wood hasn't been done in a scientific way in construction [6]. This wood provides good timber for off-ground construction and is used for beehives[2]. It has therefore been the subject of several studies to find out its characteristics to exploit it better.

II. MATERIALS AND METHODS

The materials and procedures utilized in the present tests are described in this section.

A. Materials

a) The Borassus Aethiopum Mart

The Borassus Aethiopum Mart wood chosen as a case study comes from the coastal area of Kenya, specifically Mivumoni, Msambweni sub-county in Kwale County. The tree was about 40 years old when it was cut down.

Fig. 1: Borassus Aethiopum Mart tree

The coordinates of the forest location are 4 ° 24'58.1"S 39 ° 24'06.3"E.

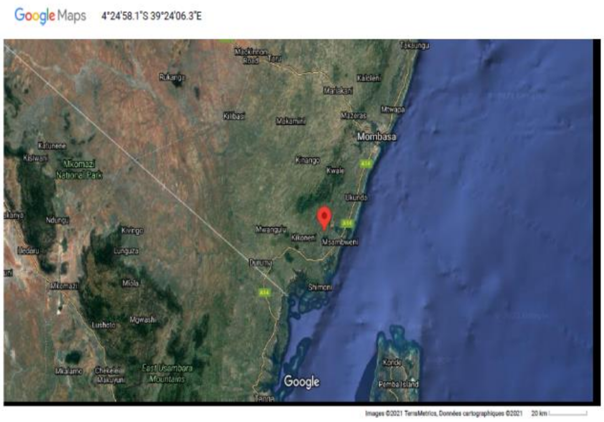

Fig. 2: Forest Location

Source: Google Map

Compression parallel to the grain test, static bending test, hardness test, shear test, and tensile parallel to the grain test was conducted to determine the mechanical characteristics of the timber.

b) Concrete constituents

The materials that were used in carrying out the pull-out test were the river sand (0-5mm), crushed aggregates (5-20mm), Portland cement(CEMI42.5 MPa), and potable water.

B. Methods

a) Timber characterization

Methods of testing small clear specimens of timber are used to determine the mechanical characteristics of Borassus Aethiopum Mart. The test specimen's form and dimensions are in line with BS 373:1957[17]. Except for the tensile test, all characterization tests were carried out on a single machine, the UNIVERSAL STRENGTH TESTING MACHINE. The maximum load capacity of this machine is 150kN. The machine's instruments are only adjusted to fit a specific test for one need or another.

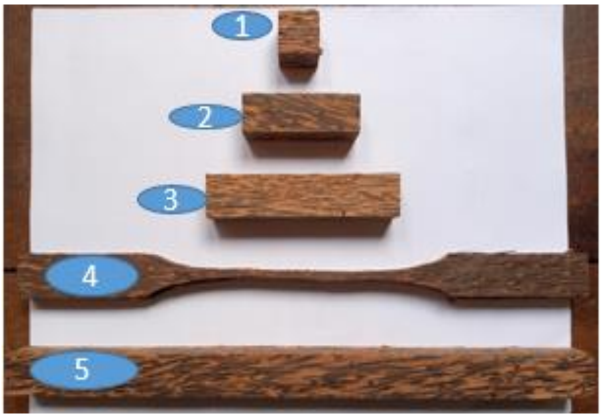

Fig. 3: Tests specimen:1-Shear; 2-Hardiness; 3-Compression; 4-Tensile; 5-Static Bending

A sample of ten elements from the upper and ten elements from the lower parts was examined. Before each test, the samples were weighed, and after testing, they were placed in an oven at 105 °C for 24 hours. The dry masses were determined for each kind of test, and the dry density and the moisture content were computed.

1) Compression parallel to grain test

The test pieces, in this case, have a section area of 20mm by 20mm and a length of 60mm. Loading between parallel plates was used to perform the test, and the load was transmitted to the specimen at a constant head speed of 0.635 mm/min. The compressive stress at the maximum load was determined by Equation 1.

$$\sigma_c = \frac{P}{A} \quad (1)$$

Where P = Maximum crushing load and A= Cross-sectional area of the test piece.

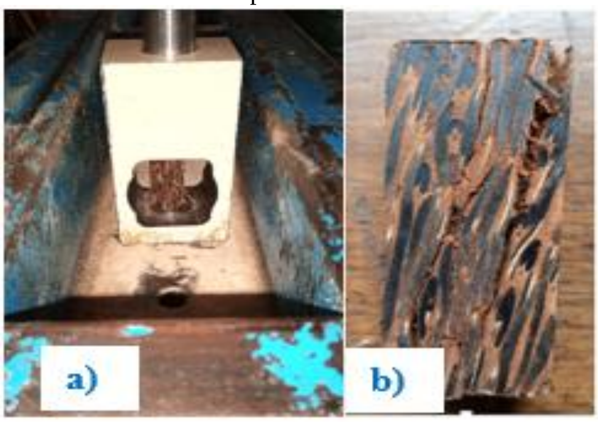

Fig. 4: Compression parallel to grain test: a) Specimen in compression; b) Specimen's failure

2) Shear test

The test specimen was a cube with a side length of 20 mm. The load was applied at a constant crosshead movement rate of 0.635 mm/min. The shear's direction was parallel to the grain, and Equation 2was used to calculate shear strength.

$$\sigma_S = \frac{P}{A} \quad (2)$$

Where P= Maximum load causing shear and A = Area in shear.

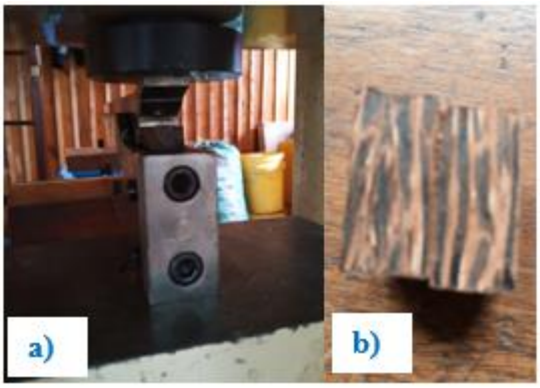

Fig. 5: Shear parallel to the grain test: a) Specimen in shear; b) Specimen's failure

3) Janka hardness test

This was done to determine the load required to force the hemispherical end of a steel bar or a steel ball with a diameter of 11.278±0.0508mminto the test piece to a depth of 5.6388 mm. The hardness tool penetrates at a rate of 6.35 mm/min. The hardness of tangential and radial surfaces was read immediately on the machine's display unit.

Fig. 6: Janka hardiness test: a) Specimen testing; b) Specimen's failure

4) Static Bending test

The bending test was used in the study to determine the Modulus of elasticity and Modulus of rupture. The three-point loading technique of the test piece beams was used in the test. The dimensions of the test specimen were 20mm by 20mm by 300mm. The loading rate was kept constant at 6.6 mm/min. The Linear Variable Differential Transducer (LVDT) measured sample deflection, and the load causing the deflection was displayed on the machine's digital display. The Modulus of elasticity and the Modulus of rupture were determined using Equations 3 and 4.

$$E = \frac{P\prime L^2}{4\Delta' bh^2} \quad \textbf{(3)}$$

$$\sigma_B = \frac{3PL}{2bh^2} \quad \textbf{(4)}$$

Where P'= Load at the limit of proportionality; P= Maximum load; Δ'= Deflection at mid-length at the limit of proportionality; L= Span of the test specimen; b= Breadth of the test specimen; h=Depth of the test specimen; σ_B=Bending strength or Modulus of rupture and E= Modulus of elasticity.

Fig. 7: Static Bending test: a) Specimen in Bending; b) Specimen's failure

5) Tensile test

The HOUNSFIELD TENSOMETER was the machine used to hold the test specimen under tension. A set of twenty-four samples were tested. The load was applied to the test piece at a constant head speed of 1.27mm/min. The tensile stress at the maximum load was determined using "(2.5)" below:

$$\sigma_T = \frac{P}{A} \quad \textbf{(5)}$$

Where P=Maximum load, A=Minimum area of cross-section of test length.

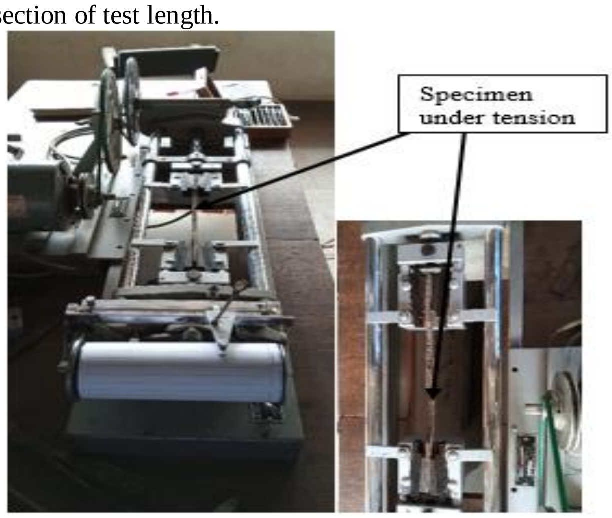

Fig. 8: Tensile test

b) Pull out test

There are four types of samples for the pull-out test. The samples composed nine elements each, and the difference between them was the anchor length. Among others, the simple Borassus (BS), the Borassus crenulated on two parallel faces (BC), the Borassus crenulated on the four faces (4BC), and the Borassus with the nails on two parallel faces (BN). The DOE method was used to design the class 30MPa concrete for this test. The concrete mix design results were taken to cast the Borassus Aethiopum Mart timber reinforcement into 150mm[3] cubes, ensuring that the Borassus timbers were vertical and in the center of the cubes.

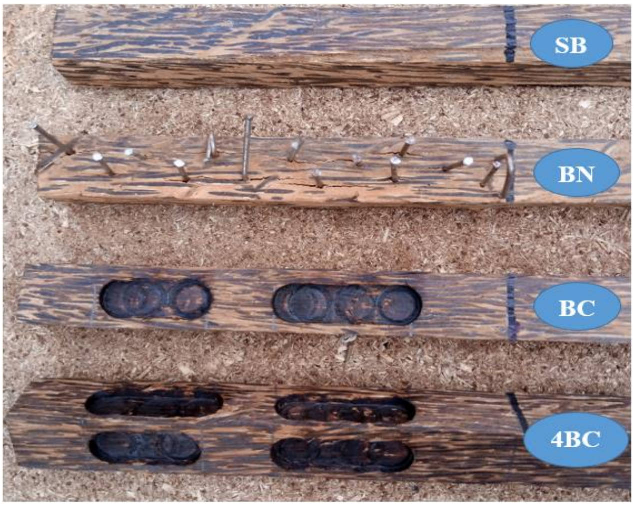

Fig. 9: Pull out test specimens

III. RESULTS AND DISCUSSION

The compression and shear test results are shown in Table I. It should be observed from this table that the compressive strength, and the shearing strength of the bottom part of Borassus, are slightly higher than that of the upper part. This disparity might be explained by the upper part's high moisture content. These findings also indicate that Borassus wood is dense at low moisture content. These outcomes exceed Samah's[18] by more than a factor of six (9.25 MPa) for compressive strength and a factor of sixteen (0.65 MPa) for the shearing strength.

Table I: Compression and Shear parallel to the grain test results

	Compression strength (N/mm2)	Shear strength (N/mm2)	Moisture Content (%)	Dry Density (kg/m^3)
Top part	56.551 ± 18.247	7.657 ± 3.009	29.495 ± 6.685	802 ±101
Bottom part	60.730 ± 12.84	8.131 ± 1.713	21.274 ± 1.647	965 ± 24

The hardiness test results are shown in Figure 10. These findings demonstrate that Borassus Wood is hard and deserving of a place among current building timbers. In this Figure, the hardiness of Borassus wood's bottom portion is 2.3 times larger than that of its upper part. Although the bottom portion of this wood contains an amount of moisture (21.274%), it is harder than Acacia decurrens (10.89kN with a moisture content of 12%)[19].

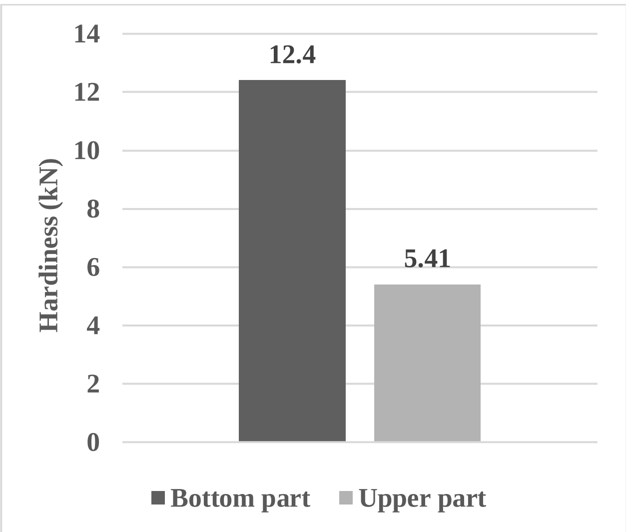

Fig. 10:Janka hardiness test results

The results of the static bending test are shown in Figure 11. The graph demonstrates that the two curves have the same paces. Each of these curves is given in three stages. The first level represents the elastic zone; the second is relatively linear, and the last is a concave curve. From point A to point C of this figure, it is apparent that the bottom part's curve is higher than the top part's because this sample can withstand a higher load than the previous one. In the illustration, points A, B, and C indicate the first fracture, sample yielding, and failure, respectively. The samples' Young's Modulus and Modulus of rupture are 3387.27 MPa and 108.23 MPa for the bottom part and 3167.11 MPa and 77.65 MPa for the upper part, respectively. The modulus of rupture of the bottom part is greater than that obtained by Moses[20] for 20 mm diameter mild steel.

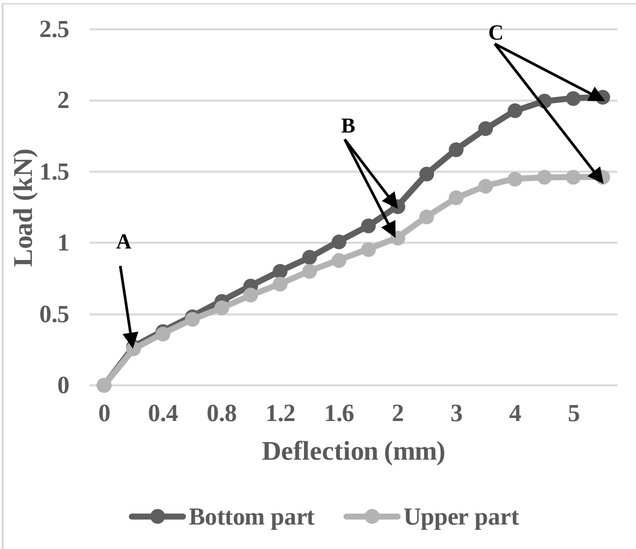

Fig. 11: Static Bending test results

Tensile strength varies from one specimen because Borassus Aethiopum is a natural material with varying defects like wood/timber[21]. To account for the imperfections, a safety factor of 0.8 was applied to tensile strength as specified in BS 5268[22]. As a result, the specific tensile strength was approximately 103.7±25.1 N/mm^2 or roughly 23% of ordinary high strength steel. This strength is slightly below that obtained by Samah (105 MPa)[23].
The results of the pull-out test are shown in Figure 12. This Figure shows that the armature of Borassus crenulated on the four sides (4BC) comes with average adhesion stress of 2.545 MPa. This value is 7.19% more than Borassus crenulated on two parallel faces BC (2.362 MPa). The crenulations then play an essential role in the adhesion of the Borassus-concrete interface.
The bond stress of Borassus with the nails (BN) is slightly higher than that of simple Borassus by about 5%. Of course, nails go together with wood, but considering the hardness of Borassus wood, the sinking of the nail caused cracks in this wood. So the use of the nails to improve the adhesion of the Borassus-concrete interface should be accompanied by preparation techniques to avoid these cracks.
Although the adhesion stress of simple Borassus (2.021 MPa) is the least in this study, it is much higher than that obtained for Bamboo (1 MPa) [24] and that obtained by Samah and Sohounhloué[18], [25]. The origin of Borassus wood can explain these differences and the strength of the concrete used to develop these tests (30 MPa in the context of this study)[26]. The standards provide for 2.8 MPa for High Adhesion steels after 28 days and 1.3 MPa for smooth round steels. Because of its performance, the Borassus timber may be used as reinforcement in concrete[18].

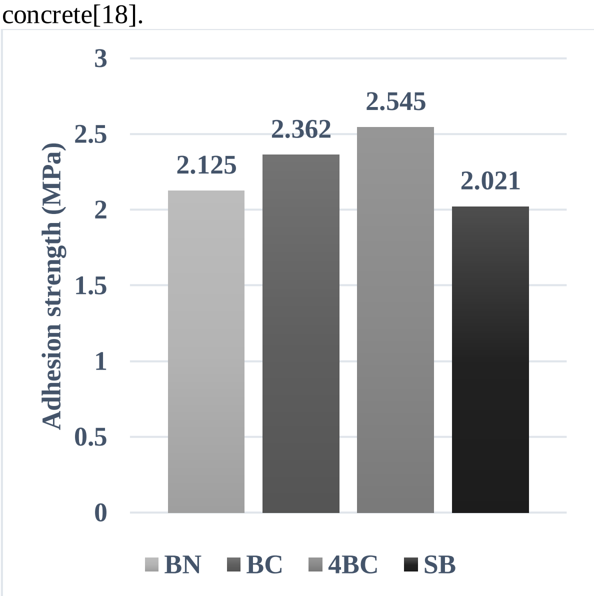

Fig. 12: Results of the pull-out test

IV. CONCLUSION AND RECOMMENDATION

The mechanical properties of Borassus Aethiopum Mart timber from Kenya were determined in this study. According to the findings of this investigation, the bottom part's mechanical properties are superior to those of the top part. When used as a reinforcement in concrete, this wood offers good adherence to Bamboo.
The bottom part of the Borassus Aethiopum Mart timber is recommended to be used as reinforcement in the concrete.

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REFERENCES

[1] G. E. Wickens, H. M. Burkill., The Useful Plants of West Tropical Africa, Kew Bull., 41(2) (1986) 471.
[2] C. K. Ruffo, A. Birnie, and B. Tenganäs, Edible Wild Plants of Tanzania, (27) (2002).
[3] L. Zongo and A. Konin, Optimisation des propriétés physiques et mécaniques de matériaux à base de biomasse végétale pour l ' éco-construction [Optimization of physical and mechanical properties of plant biomass-based materials for eco-construction], 25(1) (2018) 40–46.
[4] S. Guinko , A. Ouédraogo.,Usages et enjeux de conservation du rônier (Borassus L .) à l ' Est et à l ' Ouest du Burkin a Faso, Homme, plantes Environ. au Sahel Occident., (19) (2005) 1–6.
[5] L. Michon, K. Adeoti, K. Koffi, E.-E. Ewedje, and F. W. Stauffer, Borassus Mart ., a Purpose Palm in Togo and, Palms, 62(2) (2018) 57.
[6] M. Gibigaye et al., Etude ethnobotanique et usages mécaniques du rônier (Borassus aethiopum mart) au Bénin, Ann. des Sci. Agron., 13(2) (2010) 69–86.
[7] D. E. K. A. Siaw., The stock and socio-economic uses of Borassus Aethiopum in Abrimasu Forest Reserve of Mampong Forest District, J. Energy Nat. Resour. Manag., 1(3) (2018) 148–155.
[8] P. Bellouard, Le rônier en A.O.F., Bois et Forêts des Tropiques, 14 (1950) 117–126.
[9] A. Ali, D. Alhadji, C. Tchiegang, and C. Saïdou, Physico-chemical properties of palmyra palm (Borassus aethiopum Mart .) fruits from Northern Cameroon, 4 (2010) 115–119.
[10] B. Sambou, A. Goudiaby, F. Ervik, M. Cire., Palm wine harvesting by the Bassari threatens Borassus aethiopum populations in north-western, Biodivers. Conserv., 11 (2002) 1149–1161.
[11] O. Zongo, F. Tapsoba, H. Cisse, Y. Traore, and A. Savadogo., Modes of Use of the Palm Borassus aethiopum Mart. by the Rural Populations of Eastern and Central-Eastern Regions from Burkina Faso, Int. J. Curr. Microbiol. Appl. Sci., 7(12) (2018) 62–74.
[12] F. Gbesso, A. Adjatin, and A. A. Dansi., Aphrodisiac Properties of Hypocotyls Extracts of Borassus aethiopum Mart (Arecaceae) Collected in Central of Benin Republic, Int. J. Curr. Microbiol. Appl. Sci., 5(3) (2016) 802–814,.
[13] J. Sarkodie and S. Squire., Borassus aethiopum, A Potential Medicinal Source of Antioxidants, Anti-Inflammatory and Antimicrobial Agents, Herb. Med. Open Access, 1(1) (2015) 1–7.
[14] M. Gruca, W. Yu, P. Amoateng, M. A. Nielsen, T. B. Poulsen, and H. Balslev., Ethnomedicinal survey and in vitro anti-plasmodial activity of the palm Borassus aethiopum Mart, J. Ethnopharmacol.,175 (2015) 356–369.
[15] P.-L. Giffard., Le Palmier Ronier #Borassus aethiopum# Mart., Bois et Forêts des Tropiques, no. 116 (1967) 3–13.
[16] M. Minsha, M. Sajad, N. heen P, N. Chandran, N. an E, H. ena E., Innovative Block a New Eco-Friendly Material for Construction, Int. J. Civ. Eng., 5(5) (2018) 53–57.
[17] American Society For Testing Materials, Standard Methods of Testing Small Clear Specimens of Timber. (1957).
[18] O. D. Samah, B. K. Amey, A. Vianou, E. Sanya, E. K. Atcholi.,

Caractérisation du Rônier (Borassus Aethiopum) 'Cocker,' Технические Науки, 3(23) (2013) 140–146.
[19] B. N. Chikamai, J. K. Githiomi, and J. M. Onchieku., Strength Properties and Groups of Major Commercial Timbers Grown in Kenya, Discov. Innov., 13(3–4) (2001) 144–149.
[20] A. Moses, O. Simon, E. Oke., Comparative Analysis Of The Tensile Strength Of Bamboo And Reinforcement Steel Bars As Structural Member In Building Construction, Comp. Anal. Tensile Strength Bamboo Reinf. Steel Bars As Struct. Memb. Build. Constr., 4(10) (2015) 47–52.
[21] M. K. Ketter, T. Nyomboi, S. O. Abuodha., Investigation of Landolphia buchananii stem material properties as a concrete reinforcement material Keywords : 2(1) (2015).
[22] British Standards Institution BSI, Structural use of timber, 4(1) (1990).
[23] O. D. Samah, B. A. K, N. K.,"Determination of mechanical characteristics and reaction to fire of RNIER (Borassus aethiopum Mart.) of Togo, African J. Environ. Sci. Technol., 9 (2) (2015) 80–85.
[24] K. Ghavami., Bamboo as reinforcement in structural concrete elements, Cem. Concr. Compos., 27 (6) (2005) 637–649.
[25] A. Y. J. Sohounhloué, G. A. G. L, F. A. E. G. P., Comportement mécanique des joints interfaciaux des armatures végétales à structure périodique dans le béton : cas du rônier dans les poutres fléchies, Rev. Sci. Tech. Forêt Environ. du Bassin du Congo, 10 (2018) 77–79,.
[26] H. J. Chen, C. H. Huang, and Z. Y. Kao., Experimental investigation on steel-concrete bond in lightweight and normal weight concrete, Struct. Eng. Mech., 17(2) (2004) 141–152.