Mineralogical and Physicomechanical Characterization of the Raffia Vinifera Arecaceae Stem as Potential Reinforcement of Concrete

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Abstract: ***This work studies the physicomechanical property of the reinforced concrete by substitution of steel with raffia vinifera. The property of raw material has been investigated by mineralogical and physicomechanical analysis. The concrete blocks of 160 x 160 x 320 mm were reinforced with 2, 3 and 4 stems of the Raffia and cured by irrigation method. At each testing day, water absorption, density and compressive strength were tested. The Raffia stem is composed essentially by the cellulose type 1 with crystalline and amorpha phase. Their bulk density ranges from 0.33 to 0.97 g/cm^3 with the average value of 0.56 g/cm^3. The average compressive strength of Raffia vinifera stem is 20 Mpa. The bulk density of Raffia concrete decreases when the number of Raffia stems increases in the mixture contrary to the compressive strength which increases significantly. The best result of compressive strength (27 Mpa) was obtained with three protected Raffia stems with fluidify bitumen comparatively to the normal concrete (24 Mpa) at 28 curing days. According to the results obtained, the raffia rods can substitute the steel in light reinforced concrete structural elements using three waterproof rods of raphia arranged in a triangle.***

Keywords: Raffia vinifera stems; mineralogy, concrete; density, compressive strength

1. Introduction

Natural resources like mineral and vegetal playing a vital role in the economic activities of many countries are gaining reliable industrial attention in a world focused on environmental outcomes [1]. For several years, with the increase of the environmental concern, local materials have been broadly studied for specific applications. For instance, raffia which is a perennial plant, belongs to the group of angiosperms, the order of monocotyledons and to the subfamily of raffia. It is especially carried out in textile industries, shoes production and roof coverings [2], [3] and the thermal and mechanical characterization as potential raw material use in composite. The thermal and mechanical characterization concerns the thermal conductivity of the cork of the raffia vinifera stem [4]; the study of the creep behavior of raffia vinifera stem according to the load and the temperature for which the parameters of Burger or Schapery models [5], [6], [7], [8]; the kinetics of drying and water absorption of raffia vinifera fibers has been studied with the determination of the percentage of water absorption and the diffusion coefficient along the stem [9]; the density (0.330 ± 0.03164 g/cm3) without taking into consideration the effect of water absorption of raffia vinifera fibers and their Young's modulus (0.95–2.08) GPa were also evaluated [10]. Although many studies have been conducted on the characterization of raffia vinifera fibers, there is little scientific work about the use of raffia vinifera stem as reinforcement material in the concrete. Concrete is the mixture of local material like fine and coarse aggregates with water and binding agent (generally cement), and in some cases admixtures additives [11]. It is the most commonly used material employed for construction purpose in the world today [12], [13] according to their strength in compress but weakness in tension. Its weakness is amended by incorporation of steel bars. The high cost of steel associated to the expensive and limited raw material sources has enhanced the need to develop several indigenous materials such as bamboo [14], date palm [15] and palm stalk [16]as main or fiber reinforcement in concrete. Addition of fiber to concrete makes it a homogeneous and isotropic material. When concrete cracks, the randomly oriented fiber starts functioning, arrests crack formation and propagation, and thus improves the strength and ductility [17]. Thus, the main objective of this study is to investigate the influence of raffia vinifera stem reinforcement on some physical characteristics (density, water absorption rate) and compressive strength of concrete and evaluate their suitability in building constructions.

2. Research Significance

Arecaceae viniferous raffia is a local material much used more in handicrafts, building fences and traditional infill walls. Its structure and light weight are the main reasons that motivate us to evaluate its behavior in a cement matrix as a steel substitute; the absorption rate and the smoothness of the external surface of this plant material being high, its important factors must be taken into account in the study. Therefore, to effectively use this material, its protection against water infiltration and the creation of friction on the outer wall are proposed to improve the performance of raffia vinifera arecaceae. The results of this experimental study show that the use of raffia stems in a well-defined variable considerably improves the performance of reinforced concrete compared to unreinforced concrete and by its vegetal character, we obtain an Eco material.

3. Materials and Methods

3.1 Materials

The following materials were used for the production of the concrete.

Cement: Ordinary Portland cement (Manufactured by CIMAF), was used as the binder in the production of the reinforced concrete beams. The cement was of grade 42.5 (Figure 1a), which was in compliance with Cameroonian Standard [18].

Water: Fresh tap water (pH 7.5 and electrical conductivity 30 µS/cm) was used for the study. The water met the Cameroonian Standard [19] recommendation.

Fine aggregate: The fine aggregate used in this study was obtained from the Sanaga River, in a subdivision of the central region Cameroon (Figure 1 b). The fine aggregate was air dried at the Civil Engineering soil laboratory, Fotso Victor University Institute of Technology Bandjoun, Cameroon for two weeks. Sieve analysis was carried out on the fine aggregate to determine their suitability for concrete production.

Coarse aggregate: The coarse aggregate (Figure 1 c,d)used are bought in Bamougoum Stone quarry free from deleterious materials like silt, plant roots. According to Cameroonian Standard, coarse aggregate which are to be used for concrete production must be clean, hard, and free from chemicals or any materials that could cause the deterioration of concrete.

Raffia Vinifera stem: The partial dry stems were extracted from the swampy area located at Dja, Bandjoun West Cameroon. They were air-dried in the laboratory at an ambient temperature of 25°±4° for two weeks. The dry raffia stems were cut over a length of 280 mm with diameters varying between 20 and 30 mm (Figure 1 e) then dried at 105°C for 48 hours in the oven.

Asphalt: The fluidify cut back class 0/1 (Figure 1 f) used in this work was collected from the civil Engineering geomaterials laboratory, Fotso Victor University Institute of Technology Bandjoun. The bitumen was previously heat at 100°C during one hour then put it in marine bath at 25°C for twelve hours (EN-12591) to cooling before use to hang sand to Raphia stem.

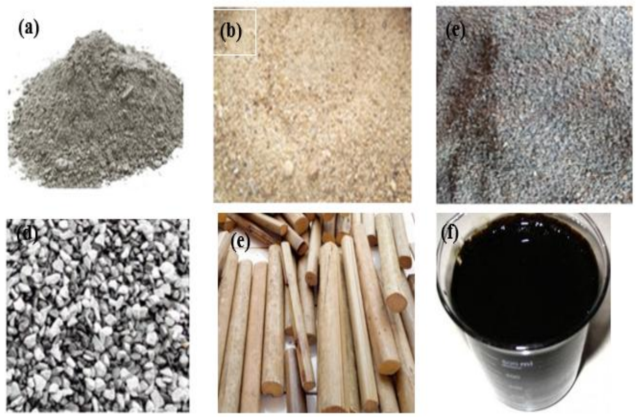

Figure 1: Raw materials usedfor the formulation of Raffia concrete: (a): Cement Portland; (b): sands (0/5); (c): Gravel (5/15); (d): Gravel (15/25); (e): Stem of Raffia; (e): fluidify bitumen

3.2 Experimental Methods

3.2.1Mineralogical Characterization of Raffia Stem

The mineralogical analysis phases were performed by X-ray diffraction (Bruker D8 Advance diffractometer) using monochromatic Cu ***Ka*** radiation with ***26*** range of 2-70° in steps of 0.020° operated at 40 kV and 25 mA using Cu-Ka1 radiation (I=1.5406 A). The interpretation of the mineral phases was carried out using the appropriate criteria [20] with the aid of an EVA software that contains a Powder Diffraction File mineral identification in the laboratory AGES (Argile Géochimie et Environnement Sédimentaire, University of Liege).

3.2.2Physical and Mechanical Characterization of Raw Materials

3.2.2.1Moisture Content

It is an important parameter which influences the behavior of raw material for any use. The moisture of our raw materials like sand and coarse aggregate has been determined by using the standard procedure [21] which consistsin drying the sample in the oven during 24 h at 105 Celsius degree and weighing it. The moisture content has been calculated with following equation (1).

$$W\ (\%) = \frac{W_w}{W_s} * 100 = \frac{W_h - W_s}{W_s} * 100 \qquad (1)$$

Where $\mathbf{W_W}$ is the water weight; $\mathbf{W_S}$ is the dry weight and $\mathbf{W_h}$is the humid weight

3.2.2.2 Bulk Density

The bulk density is the ratio of the mass of the sample to the volume (equation 2). It is determined according to French Standard (NF 21- 193). The test consists in pouring the powdered material in a dry state into a known volume until the formation of a truncated cone, then leveling with a ruler and weighing the assembly.

$$\rho_{app} = \frac{W_s}{V} * 100 \qquad (2)$$

3.2.2.3 Absolute Density

According to the French standard NF P94-054, the real density was determined according to the pycnometric method which consists in weighing the pycnometer when empty and noting its mass M_1 then introducing a mass of 25 g of dry material and reweighing the assembly noted M_2. The pycnometer is then filled with distilled water up to the mark while eliminating air bubbles and weighed; the set is noted M_3. Empty the pycnometer, clean it and fill it with water up to the mark on the stopper and weigh it, labelled M_4. Equation (3) expresses the formula use to obtain absolute density of raw materials.

$$\rho_s = \frac{M_2 - M_1}{M_4 + M_2 - M_1 - M_3} * \rho_w \qquad (3)$$

3.2.2.4 Sand Equivalent

The sand equivalent is an important parameter which gives the degree of sand purity and potential use in concrete. According to the requirements of the NF EN 933-8 [22] standards, the equivalent of sand is done on the sieve through 5 mm. the value of equivalent of the sand is obtained by following equation (4).

$$ES = \frac{ES_V + ES_P}{2} \qquad (4)$$

Where ES_V and ES_P are respectively the visual sand equivalent and the sand equivalent measured at the piston.

3.2.2.5 Grain Size Distribution

The particle size was determined by dry sieving for fraction higher than eighty microns (80µm) according to NF EN ISO 17892-4 [23]. The different raw materials have been quartering and 1500 g each of them as soaked during 24 h and washed on 80 microns sieve. The retained particles were dried in an oven at 105°C during 24h. The distribution of grains size was plotted through a series of sieves of decreasing mesh sizes: 31.5–25–20–16–12.5–10–8–6.3–5–4–3.15–2.5–2–1.6–1.25–1–0.8–0.63–0.50–0.4–0.315–0.25–0.2–0.16–0.125–0.1 and 0.08 mm.

3.2.3 Compressive Strength of Raphia Stem

The raffia samples obtained after cutting (figure 1e) are fractured in compressionand their strengths are calculated according to the formula (5)

$$R_c = \frac{10F_c}{s} \qquad (5)$$

Where Fc is the load applied to the specimen at break in kN; S is the area where the stress is expressed in centimeter square.

3.2.4 Physical and Mechanical Characterization of Reinforced Concrete with Raffia Rod

3.2.4.1 Design of Raffia Concrete Models

In order to optimize the behavior of concrete reinforced with raffia rod, we have simulated three models of raffia concrete specimens with respectively four, three and two raffia rods half-cast cylindrical specimens (figure 2).

In order to ensure the protection of the raffia in the mixture, we coated the raffia with bitumen (figure 3) which ensures the waterproofing and allows the sand to adhere to it, with the aim of provoking the adhesion between the concrete and the raffia as recommended by [24].

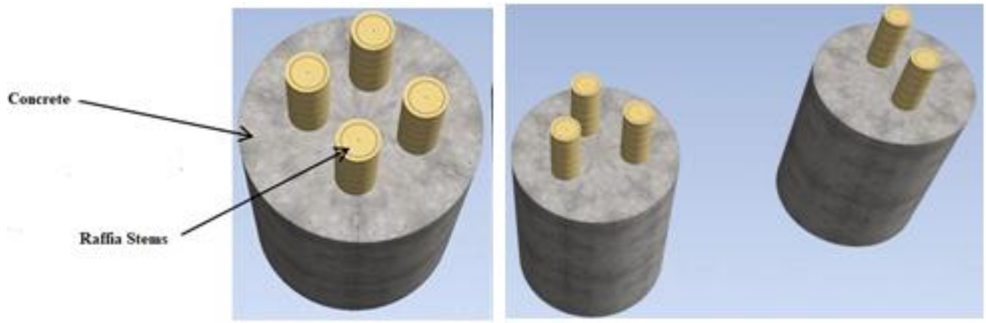

Figure 2: Design of Raffia concrete models

Figure 3: Raffia stems protected with the fluidify bitumen

3.2.4.2 Concrete Mix Design

The weight determination method was applied to measure the constituent materials (cement, fine aggregates, coarse aggregates, water and raffia) used for this study. The concrete was mixed according to the [25] method with a mixture volume ratio of 1:2:4 (cement, sand, gravel) with cement to water ratio of 0.5 and slump test of 8 centimeters for the production of the laboratory specimens. The addition of raffia rods as a substitute for steel in the concrete according to the selected variants are recorded in the table 1 below. The manufactured concrete was poured into the plastic moulds with a diameter of 16 centimeters and a height of 32 centimeters containing the raffia stems and then vibrated. These test tubes are left in the shade for twenty-four hours before being removed from the moulds and stored in water tanks at room temperature (25° C). Three formulations have been made, namely: specimens of concrete reinforced with raffia protected with bitumen (RC);

specimens of concrete reinforced with raffia not protected with bitumen and specimens of unreinforced concrete (NC), all this in order to better appreciate the behavior of raffia in concrete as a substitute to steel.

Table 1: Component of the Concrete Used and Dosage per m^3

Raw Materials	Compactness Coefficient	Absolute volume	Density	Concrete batching batching **(Kg /m^3)**	1st Variant raffia frame	2nd Variant raffia frame	3rd Variant raffia frame
Sands (0/5)	0.82	296.1	2.6	777.9	2	3	4
Gravel (5/15)		197.4	2.5	493.5			
Gravel (15/25)		211.5	2.9	632.4			
Cement			3.1	350			
Water				183.6			

3.2.4.3 Density of Reinforced and Unreinforced Concrete Specimens

The density of each beam was calculated according to the standard NF EN 13286-2 described by [26]. The concrete specimens were weighed in each test, using a precision balance. The two main dimensions (diameter and height) were measured with a digital vernier caliper of accuracy of 0.01 mm. Then, the density of each block was calculated as the ratio of the weight to the volume of the block, as shown in equation (6)

$$Density = \frac{Mass}{Volume} \quad (6)$$

3.2.4.4 Water Absorption Rate of Concretes Specimens

The test was carried out in accordance to the recommendations of BS EN 771-1:2011 [27]. Four concrete specimens of the different formulations were randomly selected and weighed before being fully immersed in water at room temperature for 24 hours. After 24 hours, they were removed from the water, re-weighed to calculate their water absorption rate according to equation (7).

$$Waterabsorption = \frac{Ma - Mb}{Mb} \quad (7)$$

Ma = weight of block after soaking in water; Mb = weight of block before soaking in water

3.2.4.5 Compressive Strength of Specimens

The compressive strength of the concrete specimens was carried out by using Digital Display Hydraulic Concrete Compression Testing Machine; Model YES-2000, Class 1 by Jinan Hensgrand Instrument Co., Ltd 2017/03. Compression tests were carried out respectively at 7, 21 and 28 days from casting. The compressive strength of the concrete specimens was calculated by relating the compressive force recorded by the machine to the surface of the specimen according to equation (5).

4. Results and Discussions

4.1 Mineralogical Analysis of Raphia Stem

The X-ray diffractogram of the raffia stem is shown in figure 4. Analysis of this diffractogram reveals the crystallinity of three peaks respectively at 2θ:16.65; 22.64 and 34.18 corresponding to the lattice planes (101, 002 and 004) of the cellulose which were described by [28]. Observation of these peaks show different intensities and enlargement is more pronounced at the peak range between 2θ, 22.64 and 34.18. This is indicative of the variation in the degree of crystallinity of the cellulose. However, the peak at 2θ: 16.65 corresponds to the diffraction of the (110) plane of amorpha crystalline cellulose, those at 2θ: 22.64 and 34.18 correspond respectively to the diffractions of the (002) and (004) planes of the crystalline cellulose type I [29]. In general, the proportion of cellulose in various hardwood and softwood plant materials varies from 40 to 45% [30]. The use of these cellulosic materials in concrete must be protected to neutralize the negative effect of cellulose on cement setting [31].

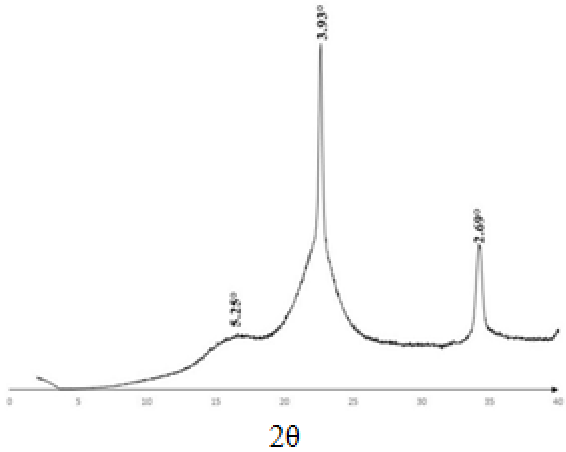

Figure 4: Diffractogram of bulk raw raffia vinifera stem

4.2 Physical Analysis of Raw Materials

Moisture Content: The result of the moisture content of the aggregate is0.6% for sand and 1.76% for gravel (Table 2) which is below the specification limit of 2 %.

Sand Equivalent: The value of the sand equivalent (Table 2) is 98.6 % higher than 80 % which corresponds to very clean sand which presents a plasticity defect due to the absence of fines and requires an increase of the water content to obtain an exceptional concrete of high resistance according to the French Standard NF EN 18.598.

Specific Density of Aggregates: The specific density of the aggregate used for the concrete production is 2.62, for the sand (0/5), 2.51 for the gravel (5/15), 3 for the gravel (15/25) and 3.10 g/cm^3 for the cement (Table 2). High specific density of the cement and aggregate contribute to the high concrete density. This indicates that the aggregates used for the study is within the accepted specified values for concrete production in accordance with [32].

Bulk density of Raffia vinifera stem: The result of apparent density of Raffia Vinifera stem is illustrated in figure5. These values range from 0.33 to 0.97 g/cm^3 with the average of 0.56 g/cm^3 in comparison with the values found on the density of raffia vinifera fibers by [10], which were 0.33 g/cm^3. There is an increase in the apparent density due to the phenomenon of water absorption of the fibers during the tests. This increase in density illustrates the need to protect the surface of the raffia stems before any use as a substitute for steel in reinforced concrete.

Table 2: Physical Characterization of Raw Material for Raffia Concrete

Raw materials	Moisture (%)	Sand equivalent (%)	Specific Density ρ_r(g/cm^3)
Sand (0/5)	0.60	98.8	2.62
Gravel (5/15)	1.72	/	2.51
Gravel (15/25)	1.72	/	3.00
Cement	/	/	3.10

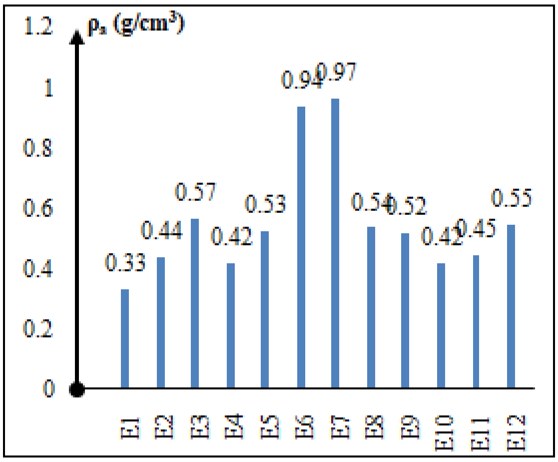

Figure 5: Apparent Density of Raffia Vinifera Stem

Particle size analysis
The result of the granulometric analysis of the aggregates is shown in figure 6. The observation of these curves shows that the granulometry is spread for sand 0/5, tight for gravels 5/15 and 15/25. The concrete formulation according to the [25] gives the volume proportions of 42% for sand 0/5, 28% for gravel 5/15 and 30% for gravel 15/25. Sand 0/5 is well graded with a silt content of 5%. This value of 5% is lower than the 6% generally allowed for the silt content of fine aggregates used for concrete production [26]. The work of [33] showed a decrease in compressive strength from 5 to 3 MPa when the silt content in the mix was increased from 7 to 9%. This shows that the content of silt or fine particles influences the strength of concrete. Thus, the fines content of 5% in the sand 0/5 will not influence the strength of the raffia concrete.

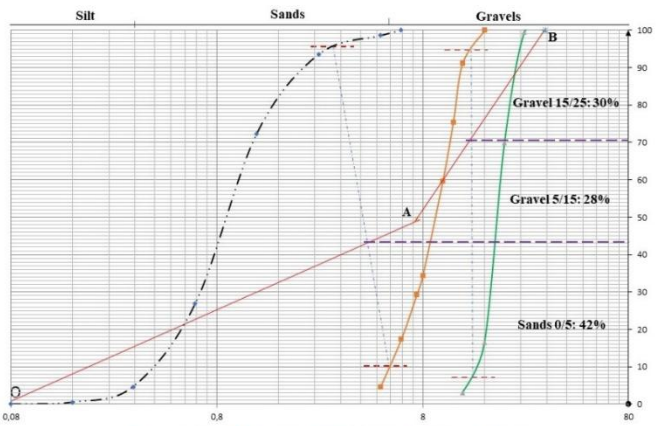

Figure 6: Granulometric Analysis and Volumetric Proportion of Aggregate by [25].

4.3 Compressive strength of the Raffia stem

The compressive strength test results of the Raffia stems are presented in figure7. Those values of compress strength range from 9 to 32 Mpa with the average of 20 Mpa. The average compressive strength of 20 Mpa is lower than 24 Mpa found by [9] on Raffia stem. This natural material can be used to increase the resistance of cementitious matrices in compression of composite materials use in civil engineering.

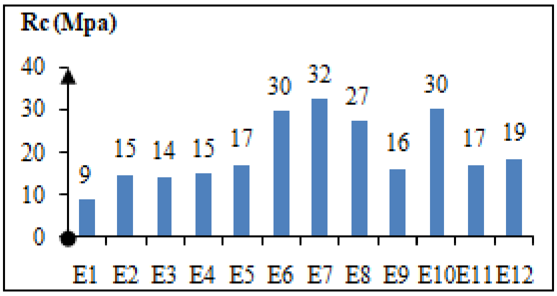

Figure 7: Compressive strength of the Raffia stems

4.4 Bulk Density of the Raffia Concrete

The concrete density of all samples decreased with increase curing days (figure8). At 28 days, the unreinforced concrete (NC) shows the highest density (2345 kg/m^3), while the four stem Raffia reinforced concrete has the lowest density (2141 Kg/m^3).[34] reported a similar trend for sawdust reinforced blocks, where the density decreased from 2400 Kg/m^3 to 1800 Kg/m^3, as the sawdust content increased from 0% to 20%. In contrast, [35]observed an increment in concrete blocks density, as the steel fiber reinforcement increased; which they attributed to the higher steel fiber density compare to that of the fine aggregate they replaced.

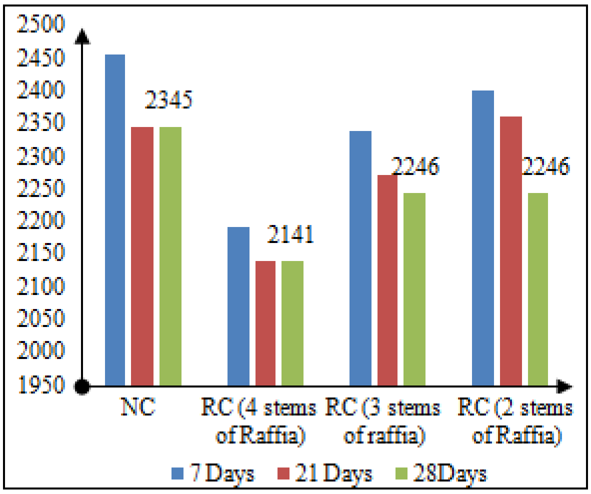

Figure 8: Bulk density of Raffia concrete formulation

4.5 Water Absorption Rate of Raffia Concrete Formulation

The water absorption rate of numerous formulations of Raffia concrete is illustrated on figure9. On this figure, we remarked that natural concrete (NC) and concrete raffia (RC) with protected stem have similar water absorption rate which is 8 %. On the contrary, the proportion of water absorption of raffia concrete with unprotected stem increase (8-14%) with the number of stems. This means that, the number of protected stems does not influence the water content of concrete.

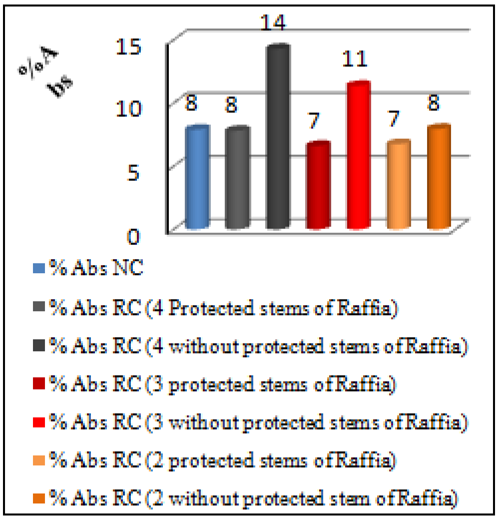

Figure 9: Water absorption rate of Raffia concrete formulation

4.6 Compressive Strength of Raffia Concrete

The compressive strength of the raffia concrete samples is presented in Figure 10. Compared with the control samples (NC), the raffia stem inclusion increases the compressive strength independently on the number of stems used. The unreinforced (control) concrete (NC) which was considered as a reference for the evaluation presents the compress strength of 24 MPa. The raffia concrete with three stems has the best compressive strength (27 MPa) when compared to the other concrete samples with four (20 Mpa) and two Raffia stems (26 Mpa). Those values remain weak compared on compressive strength of 39.68MPa found on reinforced concrete with Piassava Fiber [36]**.** For all the reinforced raffia concrete cases, statistically, the number of stems has significantly affected the compressive strength of the concrete samples but the disposition of stem influences the compress strength on the concrete because the triangular disposition is very stable. As a result of these tests, we can conclude that raffia concrete with three (03) and two (02) rods are favorable for the construction of elementary civil engineering structures working in compression.

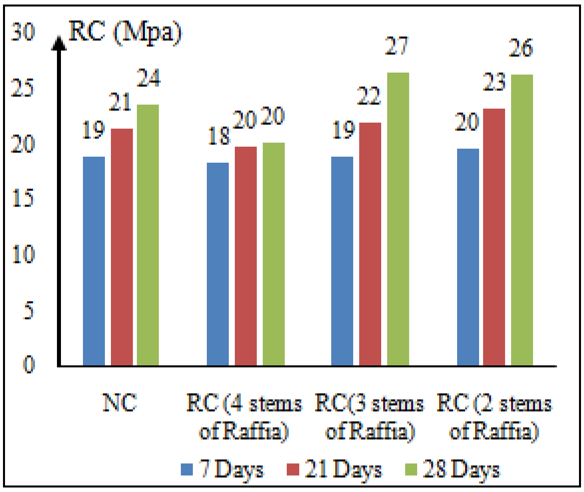

Figure 10: Compressive Strength of Raffia Concrete Formulation

5. Conclusion

This study has focused on the mineralogical and physicomechanical characterization of Raffia Vinifera Arecacea and evaluated their behavior when reinforced in concrete samples. The mineralogical analysis of Raffia stem has shown the occurrence of cellulose type 1 characterized by crystalline and amorpha phase. The physicomechanical analysis of Raffia stem expressed the bulk density of Raffia stem range from 0.33 to 0.97 g/cm^3 with the average of 0.56 g/cm^3. From the same perspective, the compress strength ranges varied from 9 to 32 Mpa with the average value of 20 Mpa. The incorporation of Raffia stems protected with fluidified bitumen in concrete decreases the bulk density of concrete depending on the number of Raffia stalks but does not influence the absorption rate of raffia concrete contrary to the reinforced concrete with unprotected stem of raffia. This is to say, the number of raffia stem protected increases the compressive strength of concrete significantly. The best result (27 Mpa) has been obtained with the reinforcement of three Raffia stems comparatively of normal concrete (24 Mpa) at 28 curing days.

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Code availability: Can be provided when the paper is going to be accepted.

8. Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

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