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Mechanical Characterization of Rhecktophyllum Camerunense (RC) Fiber Reinforced Concrete

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Abstract

This work presents the development and mechanical characterization of a concrete reinforced with plant fiber extracted from Rhecktophyllum Camerunense (RC), a plant found in the regions of Center and South Cameroon. A comparative study between ordinary concrete and concrete reinforced with RC fiber at different percentages (0.1%, 0.2% and 0.3%) was carried out. The mechanical characterization of the material consisted in studying the flexural, compressive and splitting tensile strength by using cylindrical specimens of dimensions 160 × 320 in accordance with standards EN 12390-3 and EN 12390-6. The study of the mechanical properties was completed by the three-point bending test using prismatic test specimens of dimension 40 × 40 × 160 made according to the EN 196 standard. It emerges from this work that the addition of RC fiber improves the mechanical properties of concrete up to 0.2% with a peak at 0.1% of fiber corresponding to respective increases of 9%, 16% and 6% of the values of mechanical resistance to compression, flexion and tension after 28 days. From 0.3% of fiber, the values of the mechanical characteristics of the composite drop to values lower than those of ordinary concrete. The density reduction rate at 28 days is about 10% compared to the mass of ordinary concrete. These results allow us to conclude that the RC fiber could be valorized for the production of lightweight concrete.

Keywords

Reinforced Concrete, RC Fiber, Mechanical Properties, Lightweight Concrete

1. Introduction

Concrete is one of the most used materials of the 21st century in the field of housing [1]. In order to improve its mechanical properties in service, its steel fiber reinforcement is used most regularly. Nowadays, world population growth is creating more and more need for space in large cities, forcing builders to opt for taller and taller buildings. This constraint requires players in the field to look for a solution for the production of increasingly lightweight materials. In addition, the requirements of reducing environmental pollution in the housing sector require a greater focus on ecological materials. The reinforcement of concrete with vegetable fibers, which offers a better mechanical performance/weight ratio, is one of the avenues currently being exploited by research to satisfy this dual need for light and ecological materials. In the literature, several articles demonstrate mechanical and physical improvements with the incorporation of fibers in cementitious materials [2]-[7]. The technological characteristics and low cost make fiber-reinforced concrete attractive to the building sector. Natural fiber-reinforced concrete is known to be an advantageous alternative and less harmful to the environment since it comes from plants [6]. Fibers attenuate the progression of micro-cracks, thus preventing sudden rupture [6].

Plant fibers are very diverse in their species. They are found in the roots, the trunk, the branches, the fruits and even in the leaves of certain plants. Several natural fibers have already been studied in strengthening the characteristics of concrete such as sugarcane bagasse, coconut, sisal, curaua, pineapple, jute, date palm fibers, flax, hemp… [6]-[13] to name a few.

Rhecktophyllum Camerunense is one of those plants rich in fiber. This fiber was discovered in 1981 [14] and characterized in 2007 [15] and its characteristics argue in favor of its industrial use. This fiber is already used for net fishing. A very first characterization study of RC fiber used as a plaster reinforcement was carried out in 2012 by Betene [16]. This research has made it possible to obtain a plaster-RC fiber composite with satisfactory mechanical characteristics. Given that concrete is a fragile material in the same way as plaster, and in view of the satisfactory mechanical performances obtained with the plaster-fibers composite of RC [16], we propose in the present work to verify the influence of the RC fiber used as reinforcement on the mechanical properties of concrete.

The objective of the study is not only to develop lightweight concrete based on a new type of fiber in order to determine its mechanical characteristics, but also to conduct a comparative study with ordinary concrete.

2. Material and Method

2.1. Material Used

2.1.1. Concrete

There are several types of concrete, but the one used in this study is hydraulic concrete whose binder is artificial Portland cement (NC RS 42.5). The cement is mixed with the coarse-grained sand and the gravel of type 5/15 both taken locally.

2.1.2. RC Fiber

Cameroon's flora contains many varieties of plant life such as cotton, sisal, banana trees… Among them is the Rhecktophyllum Camerunense (RC) which is abundant and found in the Center and South regions of the country. It has the morphology of a climbing plant with aerial roots. The fibers are taken from the roots. The roots exploited to extract the fibers used in the present study were cut from Nguibassal, a locality in Nyong and kéllé Division of the Center Region of Cameroon (**Figure 1**). The different steps of extracting the fibers from the roots are those used by Ntenga in 2007 [15]. This method is summed up in the following three (3) points:

1) Lightly hand-thresh the RC root.

2) Immerse the threshed roots in a large container of cold water and cover for two weeks (retting). This promotes the rotting of threshed roots;

3) Wait two to three weeks after immersion, then wash the aerial roots thus obtained. This washing removes all the dead skin and reveals the fibers, the fibers obtained are finally dried.

The RC fiber is more elastic than sisal (its mode of breakage allows it to be qualified as fragile) but the RC fiber is more elastic and ductile. The physical and mechanical characteristics of the RC fiber obtained in 2007 by Ntenga [15] are as follows: Apparent density: 0.947 g/cm^3; elastic modulus: 1.447 - 17.056 Mpa; tear resistance; 0.150 - 1.738 GPa.

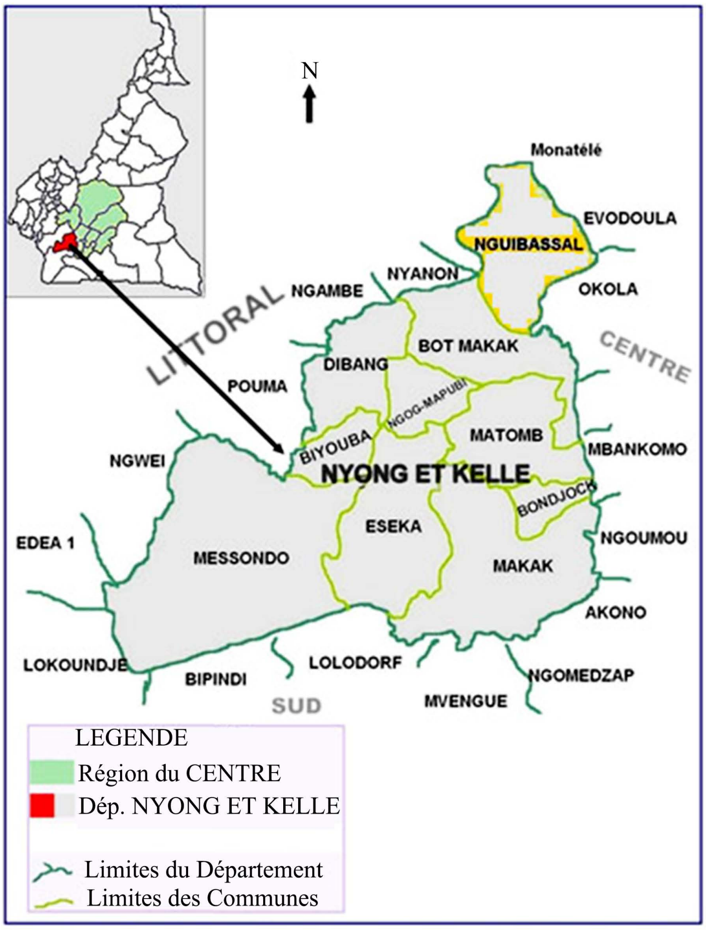

Figure 1. Map of Nyong and Kelle division, Cameroon.

2.2. Methods

2.2.1. Samples Preparation

The concrete was dosed at 350 kg/m^3 and the mixture of concrete and the vegetable fibers was made in a concrete mixer. The following combinations were adopted: concrete containing 0.1% of fiber (BRC 0.1), concrete containing 0.2% of fiber (BRC 0.2) and concrete containing 0.3% of fiber (BRC 0.3). The reference concrete without fiber was labeled BRC0. After mixing, the cylindrical samples were moulded in a polystyrene mould and the cylindrical ones in a steel alloys mould. The plastic domain was controlled with an Abrams cone. After 24 hours, the samples were removed from the molds and stored in water at room temperature until the tests were carried out on the 7th, 14th and 28th day. The objective was to verify the evolution of the mechanical behaviour of samples with time.

2.2.2. Measurement of Porosity and Bulk Density

Porosity measurements were carried out by the Archimedes method by respectively weighing samples in the dry state (after drying in an oven at 105˚C ± 5˚C), weighing samples in the wet state out of water and carrying hydrostatic weighings of the samples. Standard NF P18-459 [17] was used. The weighings were carried out using a precision scale balance Ceramic Instruments Srl Sassuolo of 0.01 g. The masses of the test pieces immersed in water (Mwet), in the dry state (Mdry) and in the wet state outside the water (Mair) were used to calculate respectively the values of the porosity and the density. By Formulas (1) and (2).

$$\text{Porosity}(\%) = \frac{\text{Mair} - \text{Mdry}}{\text{Mair} - \text{Mwet}} \times 100 \quad (1)$$

$$\text{Density}\left(\text{g/cm}^3\right) = \frac{\text{Mdry}}{\text{Mair} - \text{Mwet}} \quad (2)$$

2.2.3. Three-Point Bending Test

This test was carried out in accordance with BS EN 196-1 standard [18], using the EuroPress CMI10N50 machine (**Figure 2**) with a maximum compression pressure of 700 bars. For each test, six test pieces were used. The test consisted in applying to the prismatic sample of dimensions 40 mm × 40 mm × 160 mm, a perpendicular force (F) to the axis of the test piece and the direction of which is along the axis of symmetry of the beam resting on two supports 100 mm apart. The value of the force (F) applied during the test is given by a 1/1000 precision dial gauge. The maximum ultimate stress (σ) and the modulus of elasticity (E) are deduced by the relations (3) and (4) [19], where L is the length of the test piece, h vertical dimension of the specimen and I the transverse dimension of the specimen.

$$\sigma = \frac{3}{2}\frac{FL}{h^3} \quad (3)$$

$$E = \frac{Fl^3}{48\,fI} \quad (4)$$

Figure 2. Bending test device.

2.2.4. Splitting Tensile Test

The machine used for this test is Controlab type C0070N S/N: E12150 (**Figure 3**). The test was carried out according to BS EN 12390-6 [20]. Cylindrical specimens of dimensions 160 mm × 320 mm were used. The loading was carried out by hydraulic pressure which moves the upper part downwards until the specimen breaks. The specimen is centered between the two metal plates so that the axis of the specimen is perpendicular to the axis of the loading plates. The load was applied to the specimen continuously at the rate of 5 KN/s. A reading device makes it possible to record the maximum normal compressive stress for each of the specimens.

2.2.5. Compression Test

For this test, the machine used is the same as that of the splitting tensile test. On the other hand, here the cylindrical specimen is positioned between the two plates of the machine in the longitudinal direction (**Figure 4**). In order to ensure good adhesion of the plates to the bases of the test tube, the flatness of its bases is refined by applying a thin layer of soda. This makes it possible to make the measurement data obtained during the test more reliable. The test was carried out according to BS EN 12390-3 [21] and cylindrical-shaped specimens of dimensions 160 mm × 320 mm were used. The loading was carried out by hydraulic pressure which moves the upper part downwards until it breaks. The specimen was centered between the two metal plates so that the axis of the specimen

Figure 3. Splitting tensile test and compression machine.

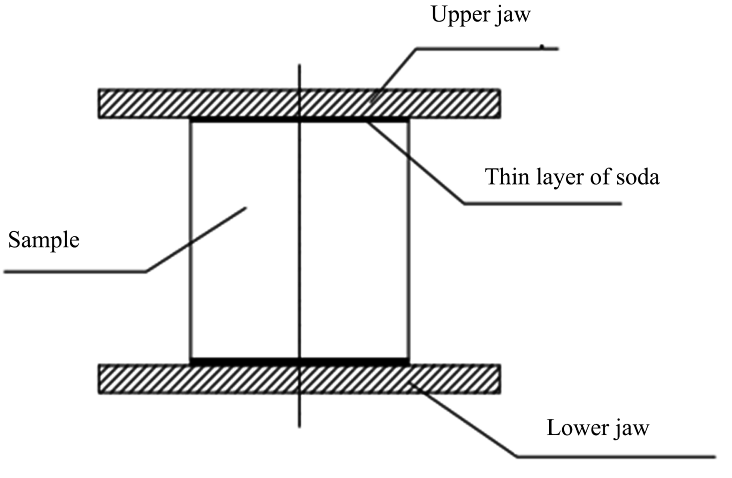

Figure 4. Diagram illustrating the compression test device.

coincides with the axis of the loading plates. The load was applied to the specimen continuously at the speed of 10 KN/s. Six test pieces were used for each test.

3. Results and Discussions

3.1. Effect of Fiber Content on Material Porosity

Figure 5 shows the variation of the porosity of the concrete reinforced with RC fiber as a function of the fiber content and the curing time. It can be seen that,

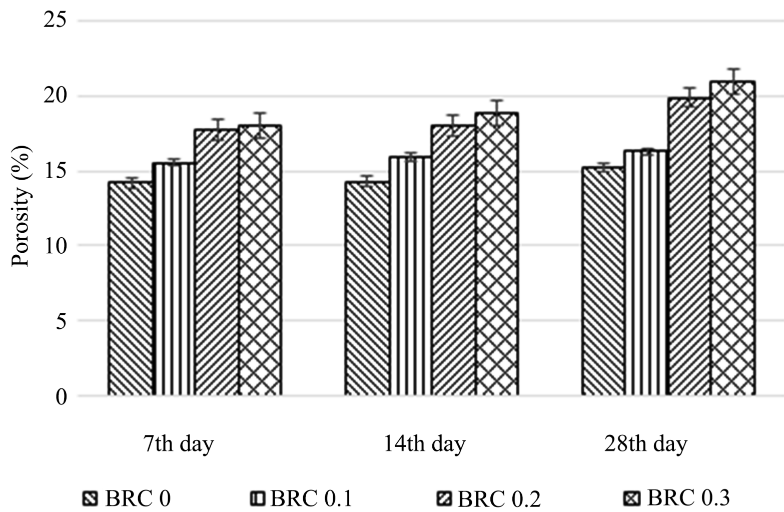

Figure 5. Porosity of composite as function of fiber content and curing time.

although the porosity of the material gradually increases as a function of the fiber content, the differences remain relatively small. Indeed, with an initial porosity of the order of 15% for ordinary concrete, the maximum increase observed does not exceed 6% for concrete reinforced at the maximum rate of 0.3% of fibers. Porosity is commonly used as an indicator of durability for cementitious materials, as it conditions the penetration of aggressive agents into the material [22]. This small increase in the porosity of the concrete reinforced with RC fibers could therefore help to ensure the durability of the material.

3.2. Effect of RC Fiber Content on Bulk Density of Material

The variations of the density of the composite as a function of the rate of addition of RC fibers during the curing time are shown in **Figure 6**. We observe in this figure that the density of concrete gradually decreases with the increase of the RC fiber. The maximum reduction rate is of the order of 10% for an addition of 0.3% of fibers at 28 days of concrete curing. This decrease in the bulk density could be attributed to the increase in the porosity of the material due to the low density of the fiber, the addition of which contributes significantly to the decrease in the density of the composite [23] [24] [25]. These results are in agreement with those of Djelal [23], Achour [26], and Galliano [27] who proved that the addition of fibers in the material considerably decreases the density because of the voids (porosity) that are created in the material. It can be noted that despite the considerable reduction in the density of the composite with the rate of fibers, the value of the density obtained at 0.3% of fibers (2 g/cm^3) remains acceptable and makes it possible to classify this concrete in the category of lightweight concretes of class D2,0 in accordance with BS EN 12390-7 [28].

3.3. Effect of RC Fiber Content on the Compressive Strength of the Composite

Figure 7 makes it possible to follow the variation of the compressive strength as

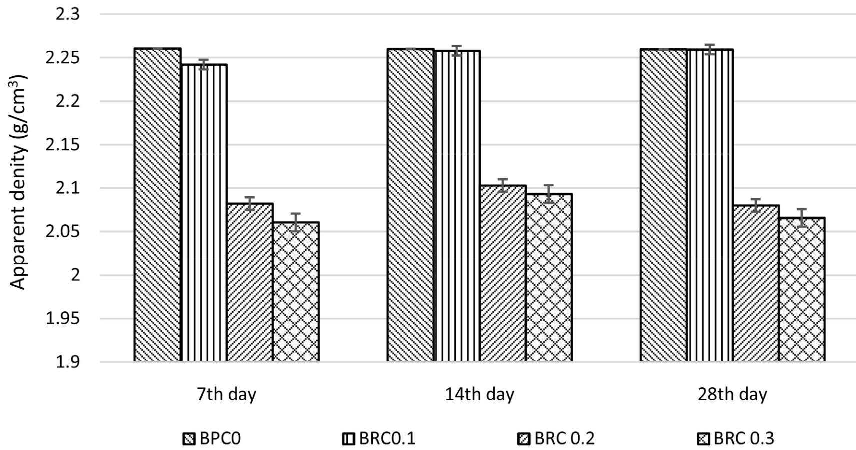

Figure 6. Density of composite as function of fiber content and curing time.

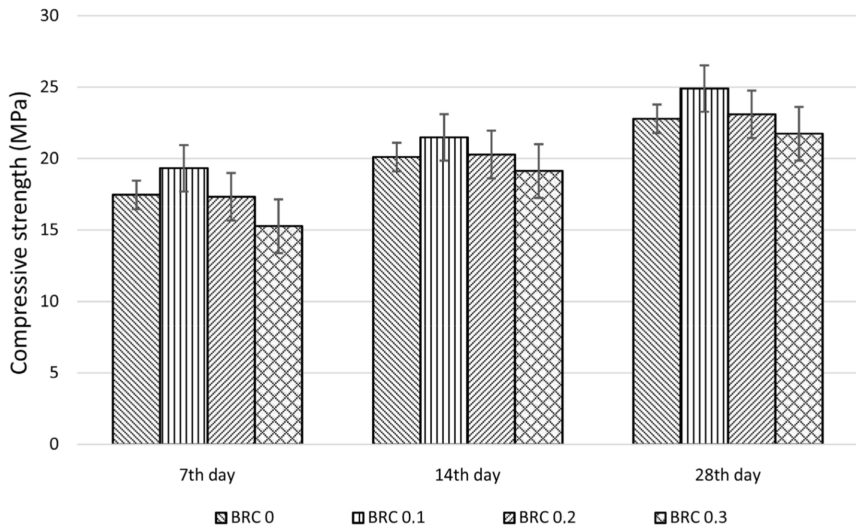

Figure 7. Compressive strength of composite as function of fiber content and curing time.

a function of the content of RC fiber and of the curing time. It can be seen that the addition of RC fiber improves the mechanical resistance to compression of the concrete and that this improvement is gradual with the curing time. A peak at 0.1% of fibers is thus observed for 28 days of cleaning. The values of the mechanical resistance to compression for 28 days of cleaning vary from 22.8 MPa to 24.9 MPa, corresponding to an increase of 9%. From 0.3% of fibers, the value of the mechanical resistance to compression of the composite drops to a value lower than that of the mechanical resistance to compression of ordinary concrete. However, the value of mechanical resistance to compression obtained at 0.3% of RC fibers (21.7 MPa) remains acceptable and allows this concrete to be classified in the category of lightweight concrete of class LC 20/22, in accordance with standard BS EN 12390-3 [21]. These results are in agreement with those of Cerezo [11] and Kriker [29] who showed that increasing the fiber ratio increases the compressive strength up to a certain fiber ratio before sometimes decreasing suddenly. This can be attributed to the dominance of the effect of fibers over that of the cement content, since the quantity of hydraulic product becomes small in front of the importance of the voids created in the mixture due to the presence of the fibers. This leads to an increase in the porous network in the reinforced concrete, which has an unfavorable effect on the mechanical resistance from a threshold of the fiber content in the material.

3.4. Effect of RC Fiber Content on the Flexural Strength of the Composite

Figure 8 shows that the variation in the flexural strength of the composite also follows the pattern of the compressive strength. The addition of RC fiber also improves the flexural strength of the material and this improvement is greatly accentuated with curing time. A peak at 0.1% fibers for 28 days of cleaning is observed (9.3 MPa), which corresponds to approximately a 16% increase over the value of ordinary concrete at 28 days of cleaning (8 MPa). From 0.3% of fibers, the value of the mechanical flexural strength of the composite drops to a value lower than that of the mechanical flexural strength of ordinary concrete (7.3 MPa).

Indeed, despite the fact that the increase in fibers in the cement matrix leads to a discontinuity of the material, we realize that the fibers reinforce the elastic behavior of the material, which allows the material to resist bending hence the gradual increase in flexural strength that we see. These results are in agreement with those of kriker [29] and Ismail [30] who found that adding fibers to concrete increases flexural strength up to a certain threshold.

3.5. Effect of Fiber Content on Tensile Strength

The variation of the tensile strength of the composite as a function of the RC

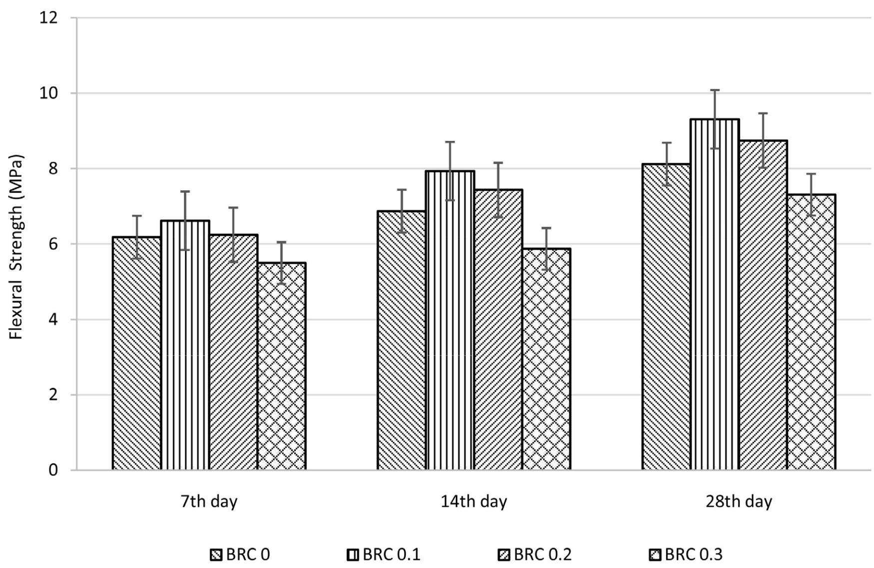

Figure 8. Flexural strength of composite as function of fiber content and curing time.

fiber rate and the curing time is presented in **Figure 9**. It is also noted that the addition of RC fiber improves the tensile strength of the concrete and that this improvement is progressive with the curing time. We thus observe a peak of the tensile strength (2.55 MPa) at 0.1% of fibers for 28 days of curing, corresponding to an increase of about 6% compared to the tensile strength of ordinary concrete at 28 days of curing (2.41 MPa). From 0.3% fibers, the value of the mechanical tensile strength of the composite drops to 2.14 MPa. These results are in agreement with those of Ismail [30] and Djebali [31] who found that increasing the fiber content increases the tensile strength up to a certain fiber content before sometimes decreasing suddenly. This can be attributed to the dominance of the effect of fibers over that of the cement content, since the quantity of hydraulic products becomes small in front of the importance of the voids created in the mixture due to the presence of the fibers. This leads to an increase in the porous network in the concrete, which has an unfavorable effect on the mechanical resistance.

3.6. Effect of RC Fiber Content on Young's Modulus of Composite

Figure 10 shows the variation of Young's modulus as a function of RC fiber

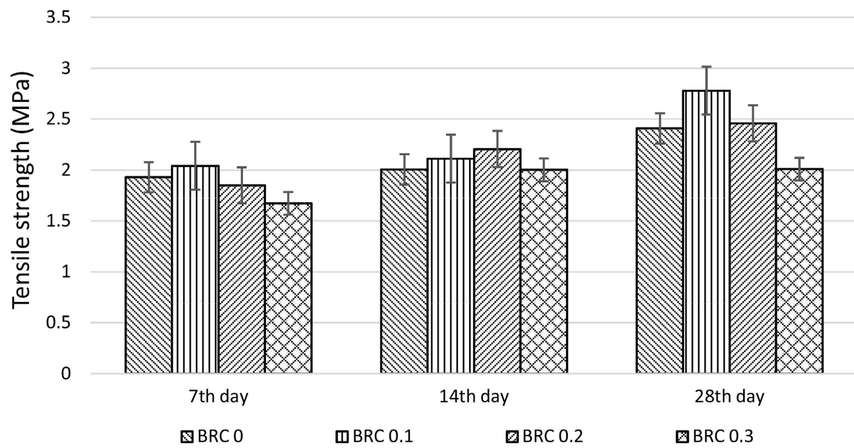

Figure 9. Tensile strength of composite as function of fiber content and curing time.

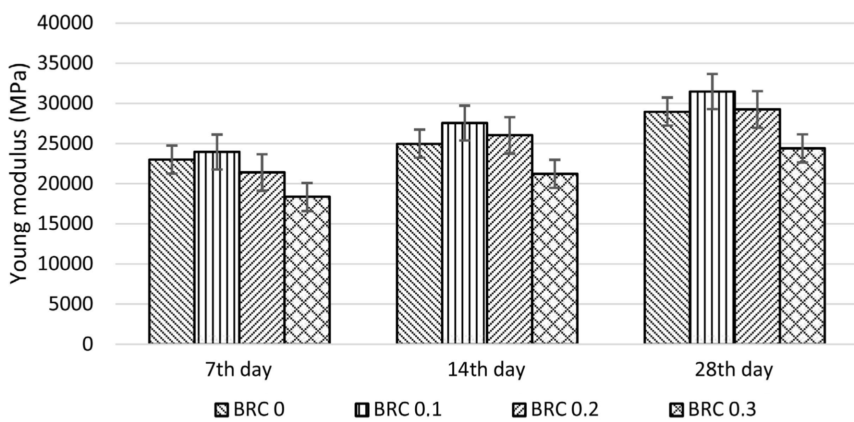

Figure 10. Young Modulus of composite as function of fiber content and curing time.

content and curing time. Young's modulus does not increase with fiber content and begins to decrease considerably from 0.2% fibers until it reaches a value lower than that of ordinary concrete at 0.3% fibers. This can be explained by the fact that the porosity of the material increases with the rate of fibers thus decreasing the stiffness of the material.

4. Conclusions

The present study allowed us to develop a new composite based on natural RC fibers, thus promoting the valorization of biomass. The effects of RC fibers on the mechanical properties of concrete have been verified and the following conclusions can be drawn:

- ✓ The addition of RC fiber in concrete improves its mechanical properties (compressive strength, flexural strength, tensile strength and Young's modulus)
- ✓ The values of the mechanical properties increase up to a fiber content of 0.2% with peaks observed at 0.1% of fibers. At the peak level, respective increases of the order of 9%, 16% and 6% of the values of the compressive strength, flexural and tensile are recorded after 28 days of cleaning.
- ✓ From 0.3% fibers, the values of the mechanical characteristics of concrete drop to values lower than those of ordinary concrete, however, the mechanical characteristics remain acceptable in accordance with BS EN 12390-3.

These results show that RC fiber-reinforced concrete is a composite that offers great potential for use as lightweight concrete in construction. As a reminder, the main problem of degradation of our fiber is related to the alkaline environment. Further research prior to this one is needed, such as the study of the durability of RC fiber in concrete with the aim of using RC fiber as a reinforcement in a cementitious matrix.

Availability of Data and Material

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Consent for Publication

All authors are willing.

Statement of Novelty

- Valorization of biomass from a tropical plant called Rhecktophyllum Camerunense (RC) for the production of lightweight concrete
- Mechanical characterization of the innovative material obtained.

Conflicts of Interest

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

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