

Full Length Research Paper

Study of physico-mechanical properties of concretes based on palm kernel shells originating from the locality of Haut Nkam in Cameroon

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This study is based on the use of palm kernel shells as aggregate in the manufacture of concrete. Several (0, 25, 50, 75 and 100%) substitutions were used in the volume fraction of the aggregates. In order to evaluate the effect of this substitution, the mechanical properties at 7 and 28 days for compression was determine, 28 days for bending and then the physical properties of fresh and hardened concrete are carried out. The results show that 25% replacement of aggregate at 28 days have the compressive stress of the reference concrete (which is about 41 Mpa). At 100% replacement, the resistance becomes very low (about 5.37 Mpa). However with 50% replacement, a reduction of the weight of the concrete is important (around 2000 kg/m³). It can at this level be classified as light weight concrete. Concerning the workability, between 25 and 50% of substitution allows obtaining the class 2 consistency, while between 75 and 100% in class 1, results corroborates the high rate of absorption of shells.

Key words: Palm kernel shells, concrete, workability, mechanical properties, physical properties.

INTRODUCTION

The palm kernel shells constitute the agricultural residues of the processing of palm nuts, produced in large quantities in Cameroon by the rural and industrial producers (CIRAD, 2014). These shells are found after oil extraction, either released into the wild or burned, thus contributing to polluting the environment. A growing need for higher habitat and infrastructure in both rural and urban areas were seen. As such, the UN (ONU, 2014) in the global urbanization prospects estimates an urbanization of Cameroon of more than 50%. This large urbanization will lead to a growth

demand in concrete which remains as everywhere in the world the material most consumed in Cameroon especially in urban areas (Bur, 2012), and by enough in rural areas because of the very low purchasing power. The use of bio based materials (Singh and Siddique, 2014) such as aggregates palm kernel shells in concretes instead of regular granulars is essential in rural areas. Through this, we will allow on the economic level: Access to local materials for Cameroonian producers, to have a low production cost for Cameroonians; an increase in GNP by creating many

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wealth; on the environmental level, the protection of the environment since some burn shells to get rid of and by the same occasion destroy the ozone layer and pollute the environment on one side and another simply throw in the nature without any prior treatment which furthermore pose a real environmental problem on the surface of the earth, to limit the environmental pollution following the overexploitation of the natural quarries of aggregates for the production of natural aggregates by the implements implemented and by the destruction of natural sites, in terms of sustainable development; the use of recycled materials by humans through simple, less expensive processes and accessible to all in contrast to ordinary aggregates and mechanically and structurally. The use of lightweight materials and constructions of structures that do not require large mechanical characteristics and also as partitioning elements in buildings.

These palm kernel shells around the world, have been used by several research in concretes as aggregates (Alengaram et al., 2011; Traore et al., 2018 and Aslam et al., 2017) especially in Africa and Asia. All these studies have based their formulation methods on the basis of ordinary concretes and also empirical methods taking into account the physical properties (Shink, 2003) of the palm nut shell as the real density and the absorption coefficient.

The aim of this work is to study the possibility of valorizing the palm nut shells in the concrete manufacturing to experimentally seek the influence of the substitution of the palm nut shells in the concrete on the physical and mechanical properties.

MATERIALS AND EXPERIMENTAL

Procedures materials

Cement

We used cement CEM II B 42.5 N in the manufacture of concrete of Belgium and in accordance with the norm to the norm NFP 15-301. The physical characteristics of this cement are recorded in Table 1 indicating the properties of the materials used.

Sand

So-called Rhine sand was used in the manufacture of concrete in Belgium and complies with the standard NFP 15-301. The physical characteristics of this sand are recorded in Table 1 indicating the properties of the materials used. The particle size analysis of this sand shown in Figure 1 shows a 0/4 granular class and consists of many fine elements of size 0/2. Its equivalent of sand according to standard NF 18-598 (8) shows us that the sand used is a clean sand with a low percentage of fine clay, good for a high quality concrete. A visual sand equivalent (ESV) of 96.65 and the piston (ESP) of 87.61 was obtained.

Aggregates

Limestone gravels were used in two continuous granular classes

2/7 and 7/14 from Belgium. The physical characteristics of these aggregates are shown in Table 1.

The palm kernel shells

The main material for concrete formulation is the palm nut shell. It comes from Famkeu village in the Bafang district of Figure 2; GPS coordinates: 5.1570500 and 10.1771000. The particle size analysis (Figure 3) shows that the palm kernel shell has a granular class of 2/20, for this study, a particle size of 4/20 was used to have continuity with the sand 0/4 used. The physical characteristics of the kernel shell are shown in Table 2.

Concrete method and formulation

This study was conducted on five composites containing different volume fractions of palm nut shell while keeping a constant volume of sand in each mixture. In view of high rate of absorption of the palm kernel shell, we have added effective water to completely hydrate cement, the added water who will be absorb by the different materials, when mixing (Shink, 2003), setting and hardening.

So the total amount of water is determined by:

$$E_{\text{total}} = E_{\text{effective}} + E_{\text{added}} \quad (1)$$

Where $E_{\text{efficient}}$ is the water which is used to completely hydrate the cement, which is given by the relation:

$$E_{\text{efficient}} = (\text{Eff} / C) \times C \quad (2)$$

E_{Added} is the water absorbed by the various constituents of the concrete (retained by the porosity of aggregates and additions); M_i is the mass of each element. W_i is the water content of each element.

$$E_{\text{added}} = \sum M_i \times A_{b_i} - \sum M_i \times W_i$$

M_i is the mass of each element. W_i is the water content of each element. A_{b_i} is the coefficient of water absorption at 24 h of each element

The total amount of water was obtained taking into account the absorption rate (Melanie Shink, 2003) of the palm nut hulls. Table 2 shows the details of the formulation, with $B_{C0\%}$, $B_{C25\%}$, $B_{C50\%}$, palm nut shell. For the compression tests, two types of cylindrical specimens, 160 mm in diameter and 32 mm in height on the one hand and 50 mm diameter and 100 mm in height on the other hand was realized. For the bending tests, the 100 mm x 100 mm x 400 mm prismatic specimens was realized. The test specimens made are demolded after 24 h and then stored in the humid room at a temperature of $20 \pm 2^\circ\text{C}$ and 100% relative humidity until the day of the test. Taking into account the two previous equations, the formulation Table 3 for a cubic meter of concrete dosed at 320 Kg/m^3 with a ratio: $\text{Eff} / C = 0.55$ was obtained Table 4.

Given the great disparity between the real densities of the palm nut hulls and that of the calcareous aggregates, the researchers opted for a formulation in substitution of the volumes. Using the grain size curves of 0/4 sand, 2/7 gravel and 7/14 gravel obtained the optimal proportions of each constituent by:

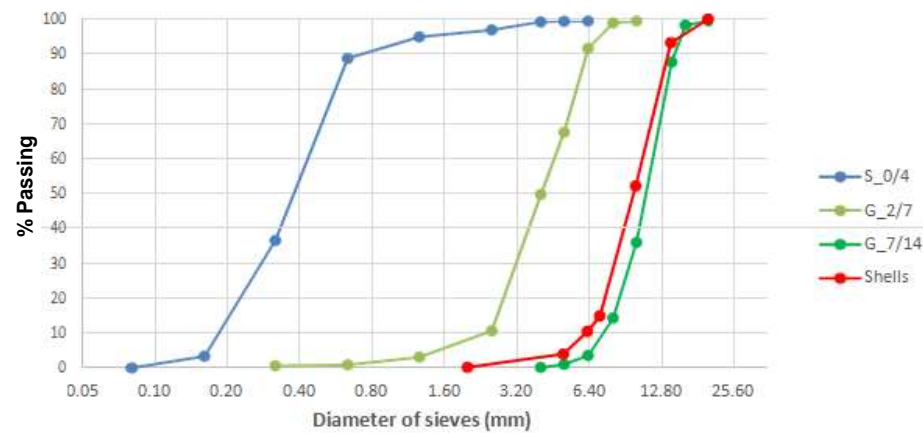
$$V_e + V_c + V_s + V_g = 1000 \text{ l} = 1 \text{ m}^3$$

Where V_e is the volume of the water, V_c the volume of the cement, V_s the volume of the sand and V_g is the volume of the gravel.

Considering that the concrete has an air content of 1% according

Table 1. Characteristics of the materials used for the manufacture of concrete.

| Reference | Type | Apparent density (kg/m ³) | Eeal density (kg/m ³) | Compactness | Modulus of fineness | Water content (%) | Water absorption (%) |
|-----------|---------------------------------|---------------------------------------|-----------------------------------|-------------|---------------------|-------------------|----------------------|
| S21 | Rhine sand 0/4 (S_0/4) | 1758 | 2600 | 0.660 | 2.20 | 0.0547 | 0.2600 |
| G34 | Crushed limestone 2/7 (G_2/7) | 1396 | 2700 | 0.679 | | 0.6240 | 0.6673 |
| G35 | Crushed limestone 7/14 (G_7/14) | 1396 | 2700 | 0.621 | | 0.624 | 0.6673 |
| | Cement CEM II B 42.5 N | | 3100 | | | | |
| | Mixing water | 1000 | 1000 | | | | |



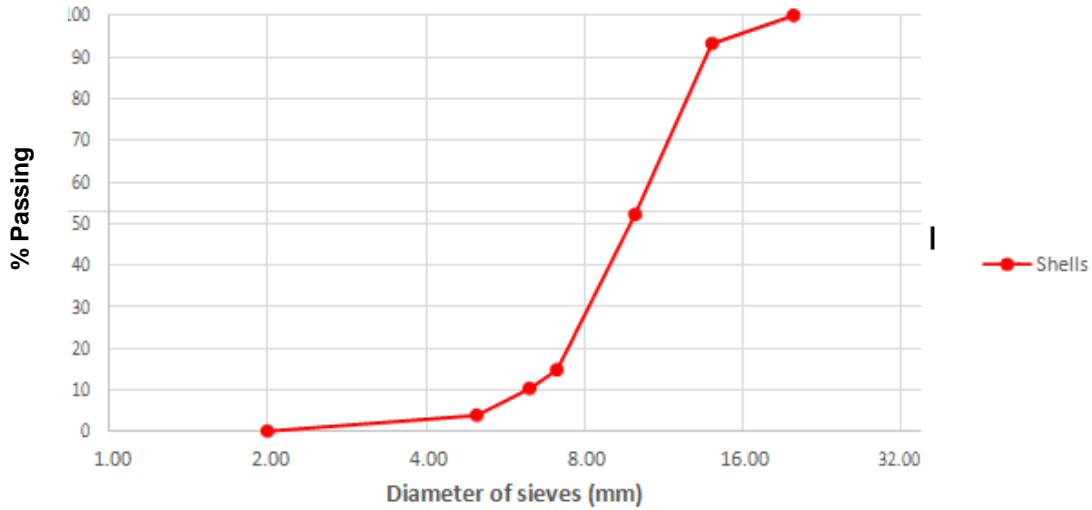


Figure 2. Particle size analysis on the palm kernel shell.

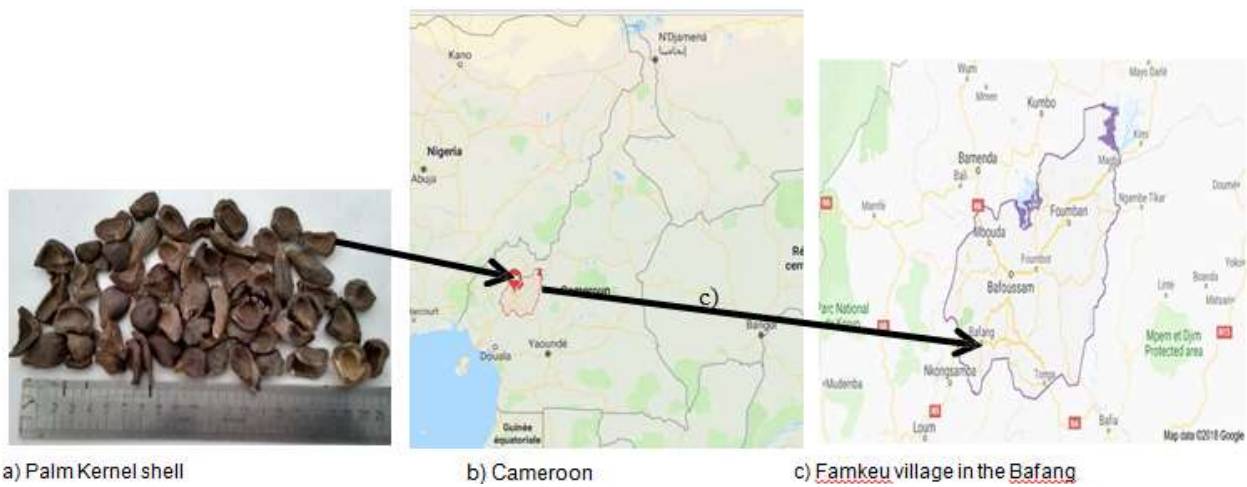


Figure 3. The palm kernel shells and the place of production in Cameroon.

to the table of Fere the total volume is given by:

$$V_e + V_c + V_s + V_g = 990 \text{ l} = 0.99 \text{ m}^3$$

Tests performed

Determination of the fresh density

According to standard NF EN 12350-6, this test makes it possible to determine the milling density of the concrete in Kg/m³ by using a container of known volume V,

$$MVF = \frac{m_2 - m_1}{V} \tag{6}$$

With m₁ mass of empty container and m₂ mass of container plus

mass of concrete contained.

(5)

Determination of the apparent density of the concrete

The NBN EN 12390-7 standard makes it possible to calculate the apparent density of concrete as a function of the mass of the sample and V its volume determined by the dimensions measured by calipers by:

$$\rho = \frac{m}{v} \tag{7}$$

Determination of subsidence and spreading

These tests according to the standard NBN EN 12350-2 are carried

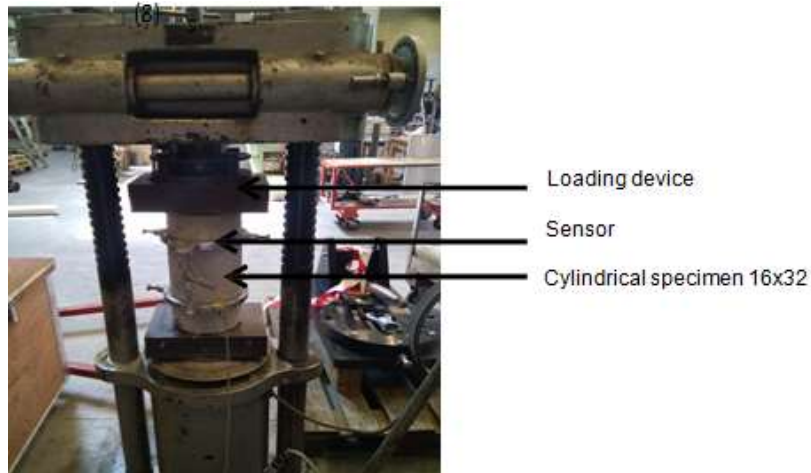


Figure 4. Device for measuring stabilized secant Young's modulus.

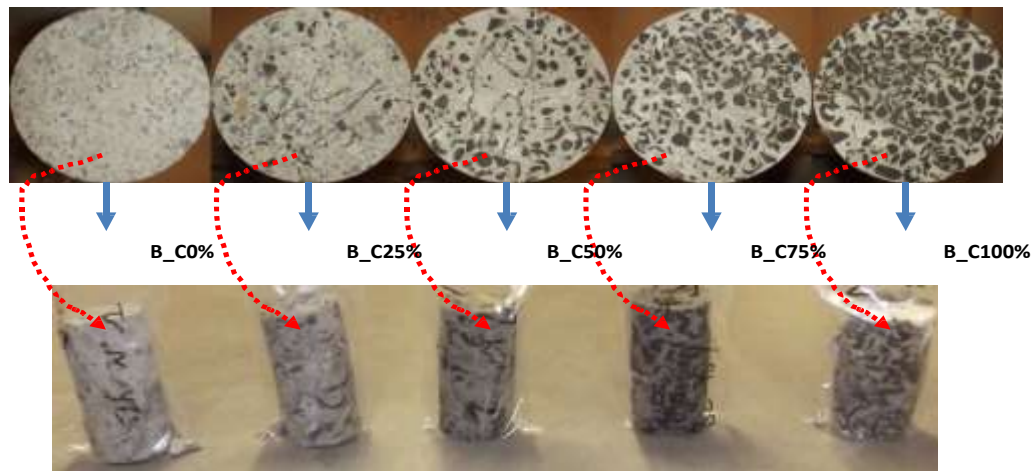


Figure 5. 5x10 test sample for compression test for different percentages of palm kernel shells (image taken in the laboratory).

out with an Abrams cone for the slump and a truncated cone for spreading just after the concrete has been left Figure 4.

Determination of compressive strength

The NBN EN 12390-3 standard makes it possible to determine the compressive strength on cylindrical samples of 16x32 and 5x10 Figure 5. The compressive strength is determined as a function of F the maximum breaking force and S the cross-section of the sample by:

$$R_e = \frac{r}{s} \tag{8}$$

Determination of the three-point bending strength

The NBN EN 12390-5 standard makes it possible to determine the

tensile strength by three-point bending on the 10x10x40 prismatic samples Figure 6. The bending strength is determined as a function of F, the maximum breaking force, the span, the width of the test piece and the height of the test piece by:

$$R = \frac{3FL}{2a \cdot x_a} \tag{9}$$

Determination of stabilized secant Young modulus

The standard NBN EN 12390-13, makes it possible to determine the secant Young's modulus stabilized on a sample of hardened concrete subjected to axial compressive stress Figure 7. On the basis of the stress- strain curve obtained by carrying out three loading cycles, this module is determined by:

$$E_{c,s} = \frac{\Delta u}{\Delta E} = \frac{u_a - u_b}{E - E} \tag{10}$$

Table 3. Formulation of the concrete dosage according to the substitution rate of the palm nut shell and mass ration.

| Dosing in kg/m ³ | Percentage of hull in volume | | | | |
|-----------------------------|------------------------------|---------|--------|--------|--------|
| | 0% | 25% | 50% | 75% | 100% |
| E = Water | 176.00 | 190.13 | 204.25 | 218.38 | 232.50 |
| C = cement | 320.00 | 320.00 | 320.00 | 320.00 | 320.00 |
| S = sand | 554.40 | 554.40 | 554.40 | 554.40 | 554.40 |
| G = gravel | 1343.36 | 1007.52 | 671.68 | 335.84 | 0.00 |
| Co = shell | 0.00 | 172.90 | 345.79 | 518.69 | 691.58 |
| Mass ratio to cement | C | 1.00 | 1.00 | 1.00 | 1.00 |
| | C/S | 1.73 | 1.73 | 1.73 | 1.73 |
| | C/G | 4.20 | 3.15 | 2.10 | 1.05 |
| | C/Co | 0.00 | 0.54 | 1.08 | 1.62 |

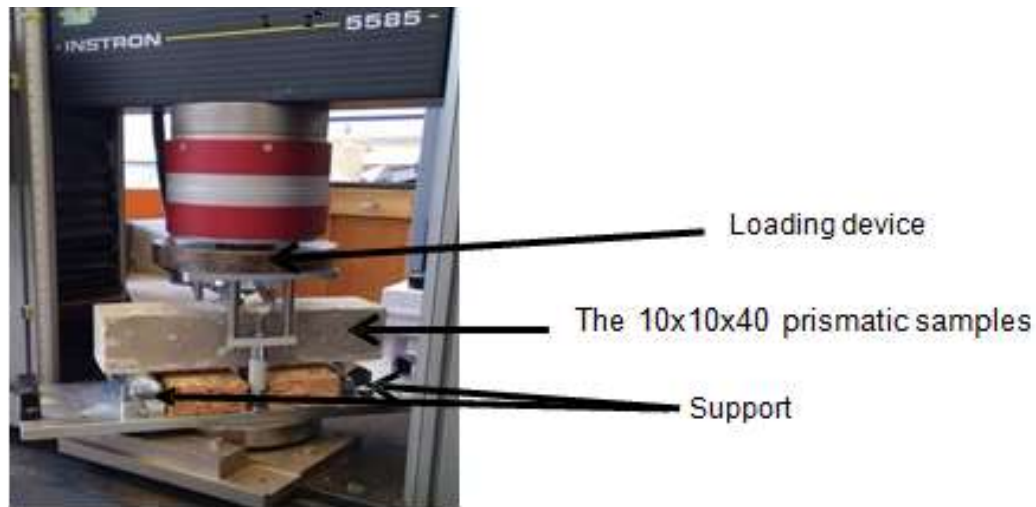


Figure 6. Bending testing machine (image taken in the laboratory).

Table 4. Percentage of concrete aggregates.

| | S0/4 | G2/7 | G7/14 | Total |
|------------|---------|---------|---------|-------|
| Proportion | X = 30% | Y = 20% | Z = 50% | 100% |



a (measure of the critical frequency)



b (measure of the wave propagation)

Figure 7. Ultrasonic test device.

era: Upper limit of stress corresponding to $F_c / 3$. erb: Lower stress limit corresponding to $0.10 \times F_c$. Ea : strain corresponding to era; Eb: strain corresponding to erb.

The ultrasonic measurement of the Eigen frequency, the propagation speed and calculation of the dynamic Young's modulus

According to standard EN 12504-4 and on prismatic test pieces: 10 cm x 10 cm x 40 cm, a transmitter and receiver was placed to measure the wave propagation through the concrete by determining the resonant frequency and the speed of propagation. The velocity of propagation is determined in the longitudinal direction and the transverse direction. Thus the dynamic Young's modulus in ultrasonic Mpa by determination of the resonant frequency is determined by:

$$E_{df} = 4n^2 l^2 \rho 10^{-12} \tag{11}$$

n is the fundamental frequency of resonance in Hz, l is the length of the specimen in mm, ρ the bulk density in Kg/m³, and the Dynamic Young's modulus in Gpa by ultrasound by determination of the velocity of propagation of waves (acoustic approaches):

$$E_{dv} = \frac{V^2 2\rho(1+\nu)(1-2\nu)}{109(1-\nu)} \tag{12}$$

V is the propagation velocity in m/s, ρ is the apparent density in Kg/m³, ν is the fish coefficient; the value of 0.2 was used for the concrete.

The velocity V was measured in two directions, the longitudinal direction to obtain VL and the transverse direction to obtain VT, and subsequently the Young's modulus in each direction, designated by EDL and EDT was respectively computed. The instantaneous Young's modulus according to BAEL 91 revised 99 and the Eurocode was calculated to establish a comparison between our Young modules obtained by tests and the empirical modules. These two Young modules are calculated respectively by:

$$E_{ij} = 11\,000 \times (f_{c28})^3 \text{ in Mpa} \tag{13}$$

With f_{c28} , the characteristic strength of concrete was measured at 28

days on cylindrical test piece.

$$E_{cm} = 22\,000 \times \left(\frac{f_{cm}}{10}\right)^{0.3} \text{ in MPa} \tag{14}$$

with

$$f_{ern} = f_{ek} + 8 \tag{15}$$

and f_{ck} is the characteristic concrete strength measured at 28 days on a cylindrical specimen.

RESULTS AND DISCUSSION

The different density

Figure 8 shows the evolution of the different density as a function of the volume content of the palm nut shell. The results show a linear decrease in the density with the increase in the palm nut content, which is in agreement with several results of the literature (Gibigaye et al., 2017 and Oti et al., 2017). The results indicate that the reference concrete at a conventional density around 2400 Kg/m³ (Neville, 2011), this value drops linearly with the hull substitution rate, at 50% of the hulls we obtain a virtually light concrete (Ke, 2009) for a density less than 2000 kg/m³ and at 100% of the shells this value is around 1600 Kg/m³. This concrete with 100% palm nut shell gives a density of about 30% less dense than ordinary concrete, however (Mannan and Ganapathy 2002) found palm kernel shell concrete 20% less dense than ordinary concrete and (Alengaram et al., 2013) observed 22 to 24% that ordinary concrete. The substitution of hulls from 50% gives lightweight concrete. We also observe a density of fresh concrete always lower than that theoretically and after hardening. The density of lightweight aggregates usually varies from 1200 to 2000 kg/m³ (Alengaram et al., 2013). This study carried out on palm nut shell concrete for 100% substitution shows that it fits well in this category.

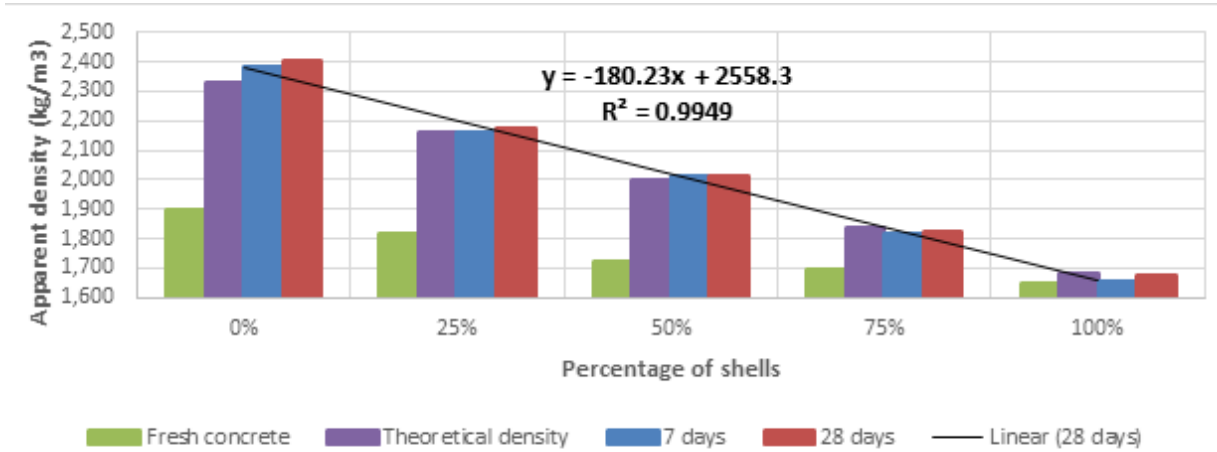


Figure 8. Results of different densities.

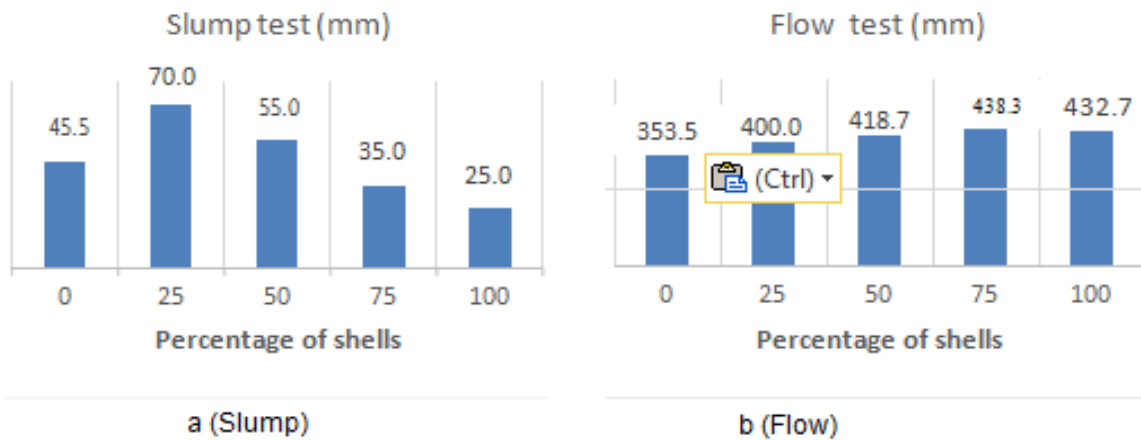


Figure 9. Workability test.

Concrete workability

Figure 9 shows that the reference concrete has a subsidence in class S1, so the concrete is very firm and concrete of consistency in class S2 with 25 and 50%, and subsequently this consistency decreases rapidly for 75% and 100% of shell to give a consistency in class S1 which ranks the concrete has more than 75% of substitution like firm concretes, several researchers had these same conclusions in their various works (Okafor, 1988; Mannan and Ganapathy 2002), Like any ordinary concrete, subsidence remains very much a function of quantity and cement, in short the E/C ratio, thus (Alengaram et al., 2013) found a slump of 20 cm palm nut shell concrete, using an E/C ratio of 0.6. There is also a decrease in sagging as a function of the degree of substitution of the hulls from 25% to 100%, this can be hard at a very high absorption coefficient of the hulls despite the water corrections add during the formulation to take into

account this physical property of the hulls. The spread remains crisscrossing reference concrete up to 75% replacement, and decreases slightly with 100 palm kernel shell.

Air content

Figure 10 shows that the air content in concrete increases with the hull substitution rate in a linear manner. The highly variable shape of the hulls, which are much more concave, and the hulls are derived from vegetable matter, lead, contrary to the reference concrete, to an accumulation of air during the mixing of the concrete. Therefore, the use of the palm kernel shells increases the content of air 5,00 occluded concrete (Alengaram et al., 2013) and for concrete 100% shell, there is an air content that remains at the limit for ordinary concrete. The results obtained here are of the same order of magnitude (3.9 - 5.5%) as those obtained

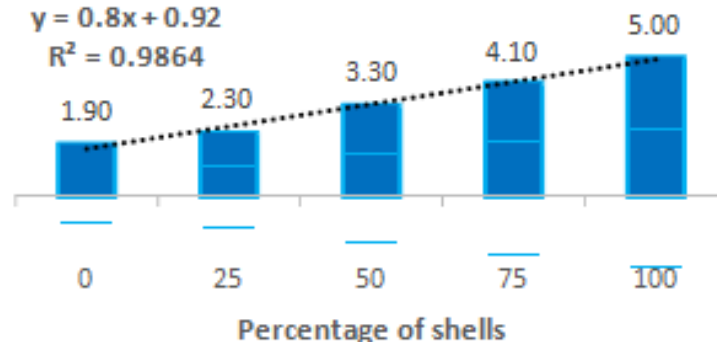


Figure 10. Measurement of air content.

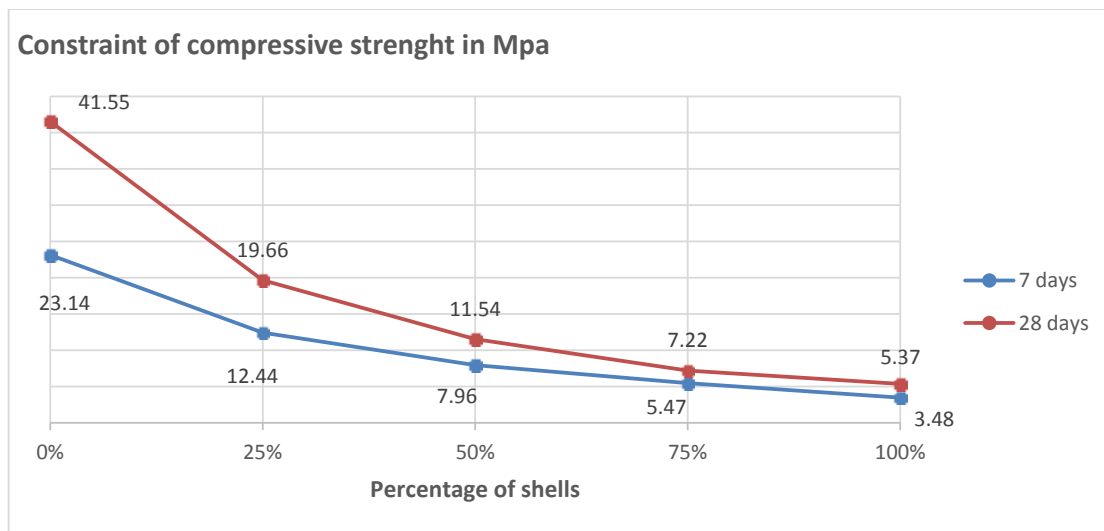


Figure 11. Cylindrical specimen test results 16x32 at 7 and 28 days.

by (Mannan and Ganapathy 2002; Teo et al., 2010).

Compressive strength

Figure 11 shows the evolution of the compressive strength on cylindrical specimens of 160 mm in diameter and 320 mm in height depending on the palm nut shell ratio at 7 and 28 days. It is observed that between 7 and 28 days there was continuous hydration process which contributed to increased resistance of the concrete with the substitution rate of at least 56%. It is also observed that at only 25% substitution of the hulls, the concrete loses more than 50% of its resistance, and this decreasing is very abrupt and fast with the increase of the shells (Aslam et al., 2017). This compressive strength at 25% substitution is of the order of 19.66 MPa, which corroborates the results obtained by (Olanipekun et al. (2006). They conclude that to obtain a compressive strength concrete of 20 MPa, the shells should not be

substituted for more than 25% of the mass of conventional aggregates, with a formulation ratio of 1: 1: 2 and 1: 2: 4 for E/C = 0.5 at 28 days of ripening for a 50% replacement; a resistance concrete equal to 11.6 MPa and a replacement strength of 5.4 MPa is obtained at 100%, which remains relatively low. Table 5 summarizes the three trend curves written for each day of the stress drop as a function of the percentage of hulls. From this table, it can be seen that the resistance drop is not at all linear but has a much exponential trend. This decrease may be related to the increase in the amount of occluded air (Baite et al., 2016) in Figure 12 shows the evolution of the compressive strength on cylindrical test pieces of 50 mm in diameter and 100 mm in height; this depending on the rate of palm nut shell at 7 and 28 days. It is observed that between 7 and 28 days, the percentage of shell decreases exponentially with the strength of the concrete in the two maturation dates, these results confirm those obtained on cylindrical specimens of 160 mm x 320 mm. Time and again; there

Table 5. Mathematical modeling of the variation of strength with the percentage of palm kernel shells.

| | Linear | 2nd order polynomial | Exponential |
|------------|--|---|--|
| Fc7 | $y(x) = -18.511x + 19.755$ $R^2 = 0.8761$ | $y(x) = 22.179x^2 - 40.69x + 22.528$ $R^2 = 0.9862$ | $y(x) = 21.29e^{-1.483x}$ $R^2 = 0.9915$ |
| | $y(x) = -33.917x + 34.027$ $R^2 = 0.8260$ | $y(x) = 50.159x^2 - 84.076x + 40.297$ $R^2 = 0.9841$ | $y(x) = 35.888e^{-2.037x}$ $R^2 = 0.9743$ |

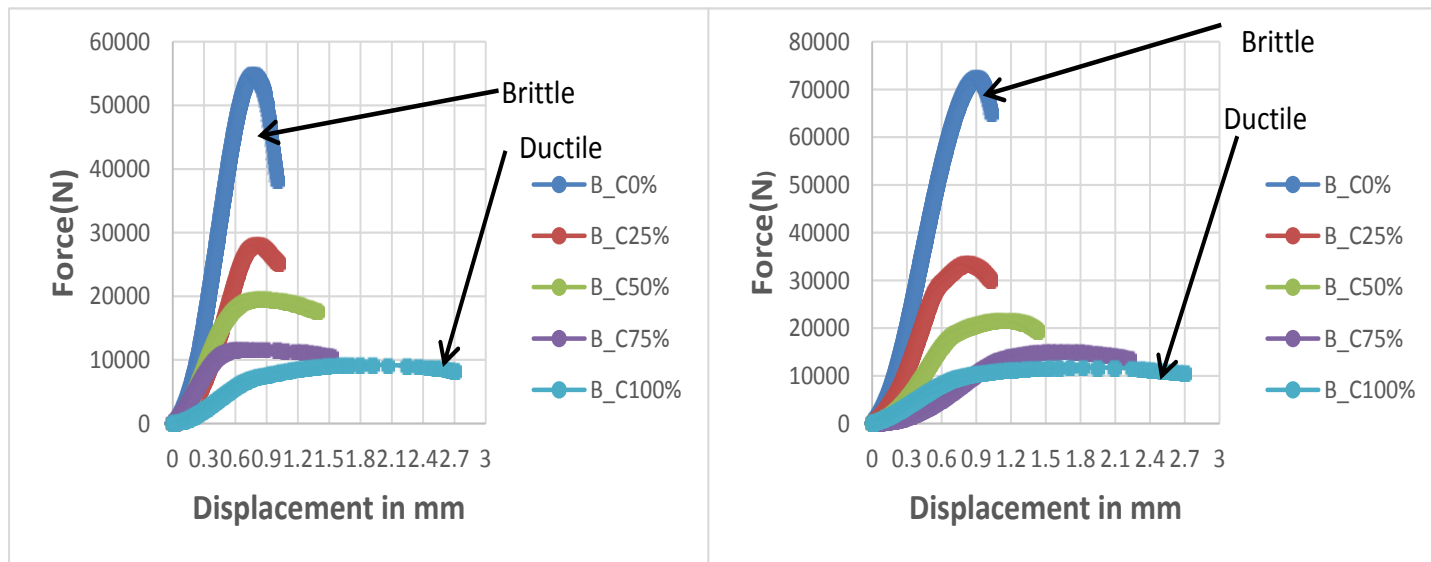


Figure 12. Results of compression tests on cylindrical specimen 5x10 : a) 7 days; b) 28 days.

is a greater deformability of the concrete, for a non-brittle fracture as the reference concrete, this is an advantage for the construction of flat elements. This translates in fact that palm nut shell concretes are more ductile than ordinary concretes that are very fragile. Figure 13 shows the effect of the size or granular class of shells; the larger aggregate increases the compressive strength.

However, all classes can be used in the manufacture of concrete depending on the availability of hulls in the region.

Ultrasound measurements

The ultrasound results are at 28j of age recorded in Table 6. According to (Yusuf et al., 2016), it can be seen that for up to 50% of hulls, the concrete remains of better quality and at 75%, a concrete of average quality and at 100%, a concrete of low quality was obtain. It is also noted that the speed and the frequency of propagation decreases with the percentage of shell, which contributes to improvement in the acoustic quality of a concrete, the concrete with 100% of hull thus presents a very good resistance to the propagation of

the waves.

Evaluations of the different Young's modules

The stress-strain curves (Figures 14 and 15) for the three specimens show a linear trend in the three loading cycles, estimates of the secant Young's modulus gives us a value of 30.63 Gpa, and a value of one third to 50% of the B_C0% for the percentage of hulls at 50% is 10.11 Gpa and a value corresponding to the tenth of B_C0% to 100% of hulls is 2.99 Gpa. The Young's modulus on the B_C100% represents 10% of the reference concrete; this drop is explained by a very big difference between the physical properties of the hulls to those of the calcareous aggregates and also a bad adhesion between the hulls and the matrix of the cement. The Young's modulus on B_C100% is much lower than the values indicated in the literature (Adinkrah et al., 2018) for light concrete which is 10 to 24 Gpa.

Flexural stress at 28 days

Depending on the percentage of the shells, there is a

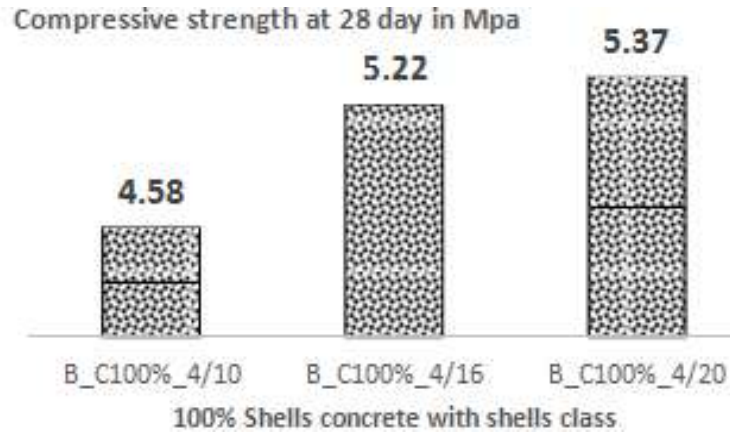


Figure 13. Cylindrical specimen test results 16x32 days and 28 days depending on granular class of shells.

Table 6. Ultrasonic Results (Resonance Frequency Measurement, Transverse and Longitudinal Propagation Velocity).

| | B_C0% | B_C25% | B_C50% | B_C75% | B_C100% |
|-----------------------|-------------|-------------|------------|-------------|-------------|
| n en Hz | 5 131 (±11) | 4 330 (±13) | 3 689 (±3) | 3 068 (±11) | 2 660 (±10) |
| v _T in m/s | 4 349.72 | 4 201.68 | 3 584.23 | 3 269.04 | 2 702.70 |
| v _L in m/s | 4 608.83 | 4 082.05 | 3 875.97 | 3 003 .00 | 2 453.99 |

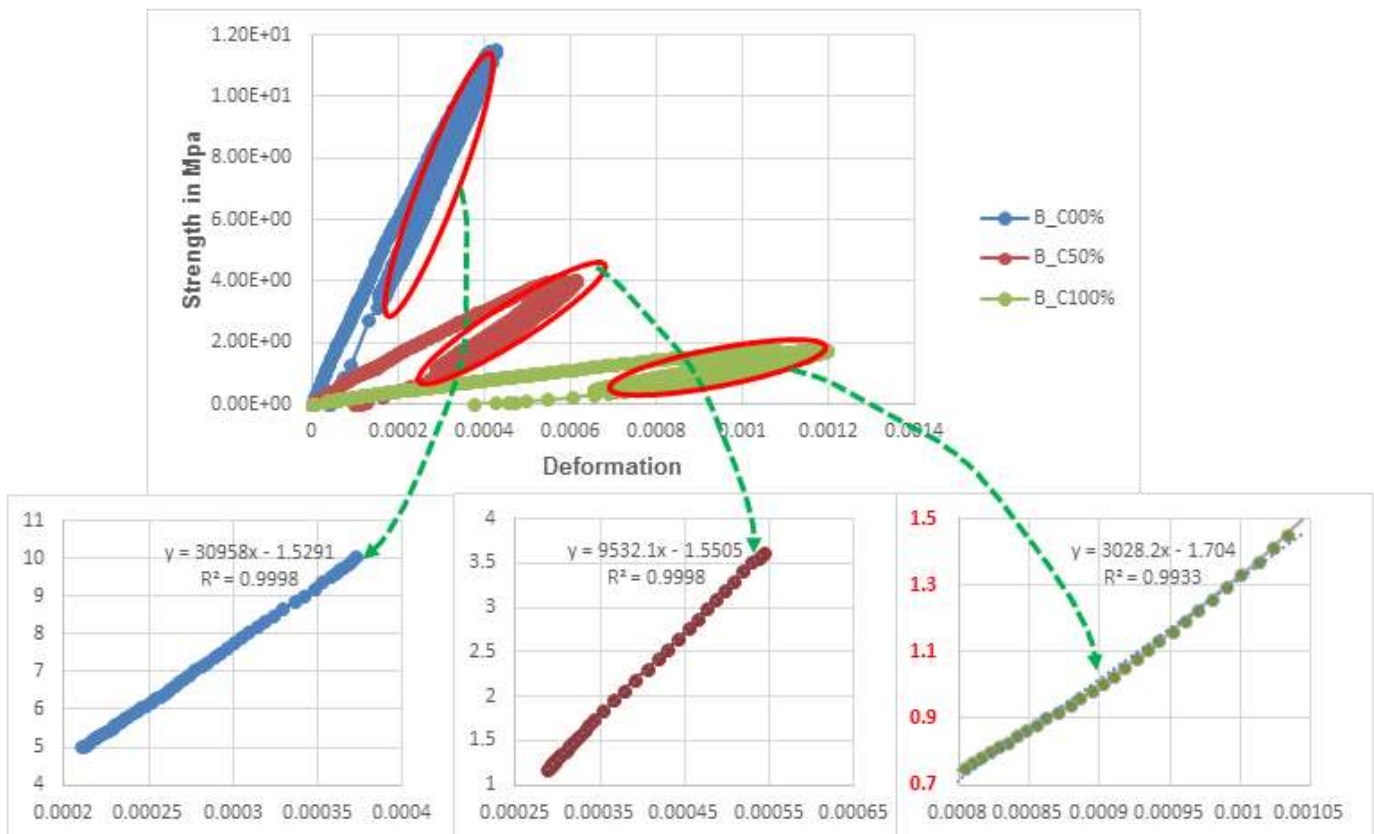


Figure 14. Results compression test on 16x32 cylindrical specimens for secant Young's modulus

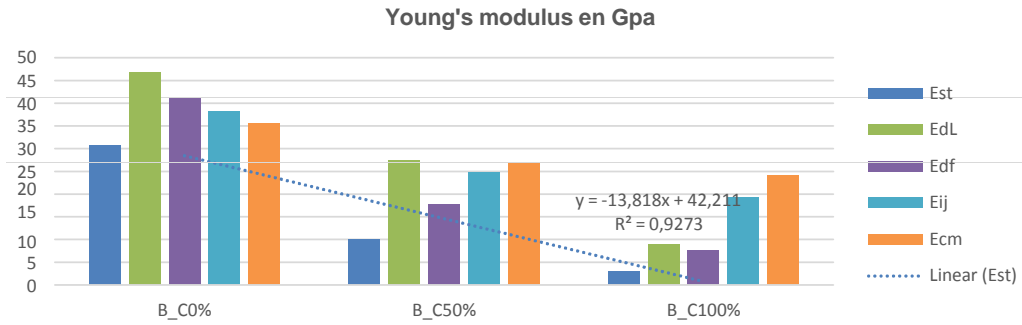
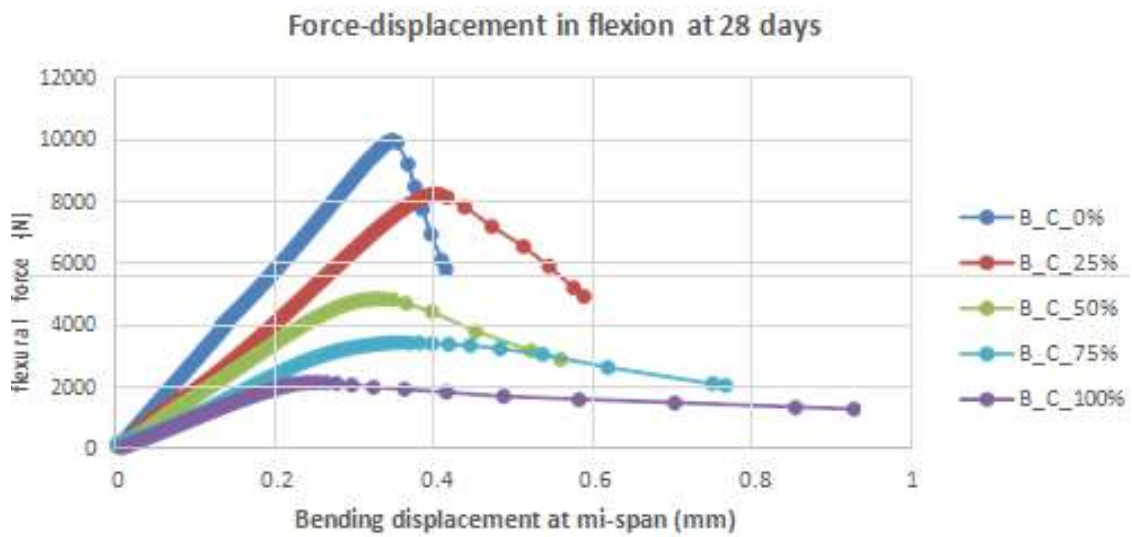
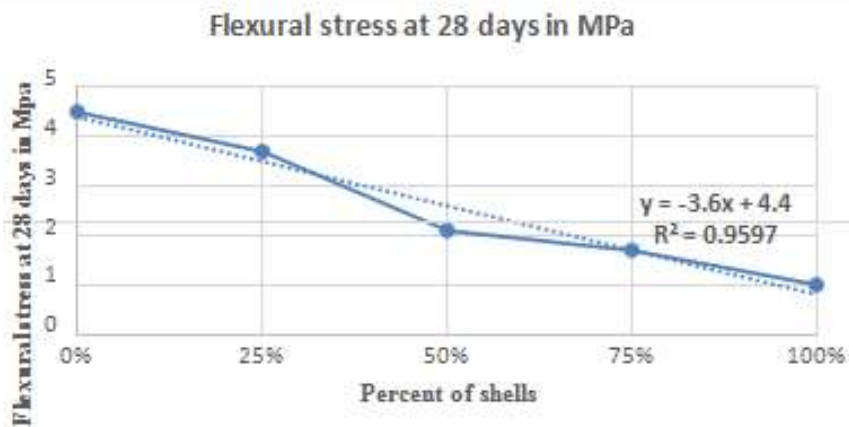


Figure 15. The calculations of the different Young's modules.



(a) Force-displacement



(b) Flexural stresses as a function of the percentage of palm kernel shells.

Figure 16. Flexural test.

nearly linear drop in the flexural strength of the concrete at 28 days (Figure 16), and for the concrete of 100%

hull there is a very low value of resistance around 1 MPa, one-fifth of the value of the reference concrete.

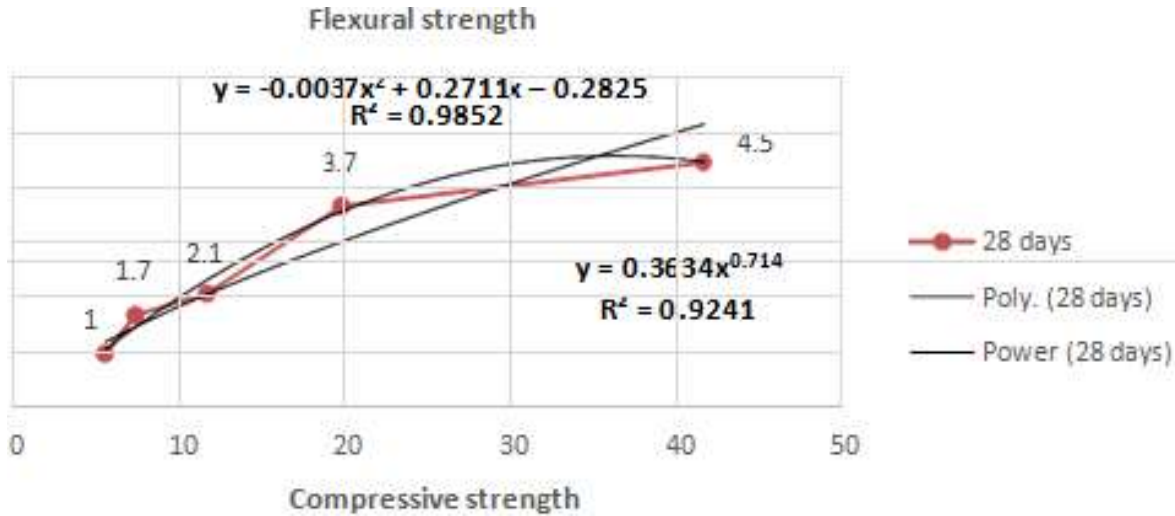


Figure 17. Correlation between 16x32 cylindrical specimen compressive strength and 10x10x40 cubic specimen flexural strength at 28 days maturity.

Correlation between parameters

$$fc_{28} = 2.10 \cdot 10^{-18} p^5 + 6.909 \tag{20}$$

Correlation between 16x32 cylindrical specimen compressive strength and 10x10x40 cubic test specimen flexural strength at 28 days maturity

Figure 17 shows the correlation between the 16x32 cylindrical specimen compressive strength and the flexural strength of the different concretes for each substitution from the reference concrete, and we obtain two possible correlations (Equations 16 and 17) with respectively one correlation coefficient of 0.9852 and 0.9241 with the first for a polynomial correlation of order 2, the second a correlation of power:

$$f_t = -0.0037(fc_{28})^2 - 0.2711fc_{28} + 0.2825 \tag{16}$$

$$f_t = 0.3634(fc_{28})^{0.714} \tag{17}$$

Correlation between 16x32 cylindrical specimen resistance and 28 day maturity density

Figure 18 shows the correlation between the 16x32 cylindrical specimen compressive strength and the density of the different concretes for each substitution from the reference concrete, and three possible correlations (Equations 18, 19 and 20) were obtained with a coefficient correlation of 0.9969, 0.9902 and 0.9769 with the first for a polynomial correlation of order 2, the second an exponential correlation and the third a correlation with power:

$$fc_{28} = 0.00008p^2 - 0.2873p + 256.25 \tag{18}$$

$$f_{e28} = 0.042e^{0.0028p} \tag{19}$$

CONCLUSION AND RECOMMENDATION

This work has been devoted to the study of a concrete base shell of palm kernels. The main objective of the laboratory is to provide the researcher in mechanical materials with data that would enable them to use this composite material safely and effectively in low demand building constructions. In addition to the physical characterizations of palm nut shells and observation with scanning electron microscopes, the mechanical tests on the formulated concrete were carried out on several volume substitutions of the palm kernel shell as aggregates in the concrete of a concrete (10 to 25%). The overall results indicate that the palm kernel shell is essentially composed of carbons and oxygens and has a very high absorption rate due to its high structural porosity and some mesocarp fibers remain on its outer surface. The 100% shells substitution rate gives results in compression and bending too low, due to the poor adhesion between the shells and the matrix, other processes can be used to improve these characteristics including the shells treatment of palm kernel or the use of plasticizers or super plasticizers in the formulation of concretes. These 100% substitution palm kernel shells concretes can be used as partitioning and filling elements in dwellings. A 50% rate gives a light concrete and with acceptable resistances for simple structures for habitats. The results obtained open up a vast field of research regarding the determination of the durability of these concretes taking into account climatic conditions in Cameroon and the improvement of these mechanical properties for more applications in the field of sustainable construction. Other notions that can be addressed include

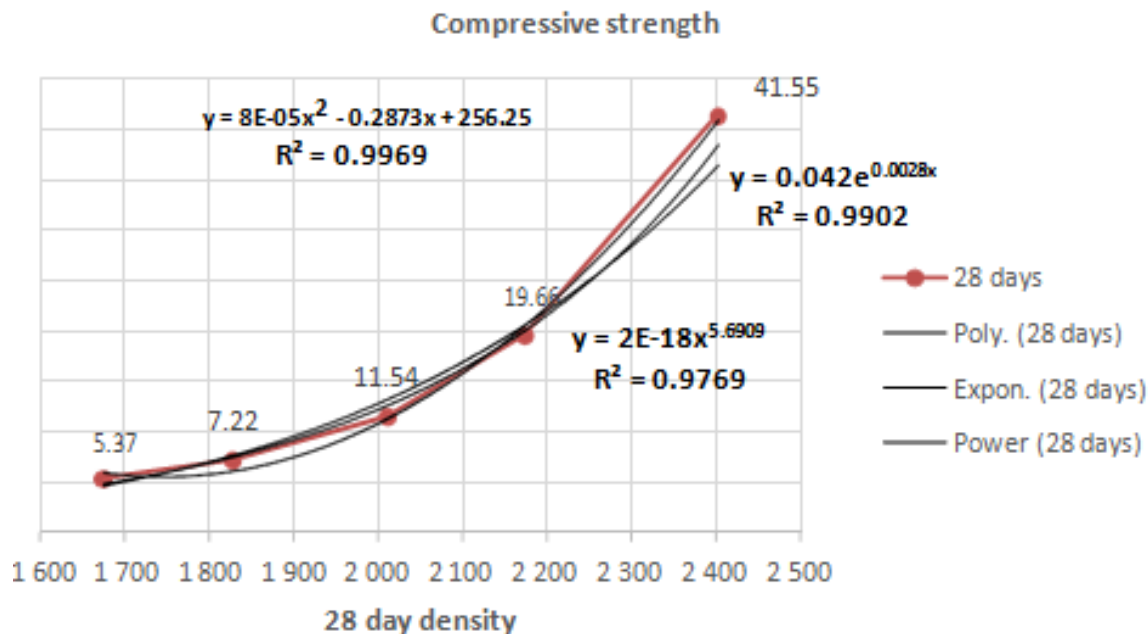


Figure 18. Correlation between the 16x32 cylindrical specimen compressive strength and the 28-day density.

the determination of gray energy, the real potential of salvaged palm hulls by long-term characterizations and the contribution to building cost savings compared to ordinary concrete

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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