CHARACTERISATION OF LIGHTWEIGHT CONCRETE IMPREGNATED WITH CEMENT AND CHARCOAL

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Abstract

This paper reports the results of a study on the formulation and characterization of lightweight concrete made with Cameroonian charcoal as lightweight aggregate. Lightweight concrete is an old material and has been known around the world for over a quarter of a century. They are experiencing a renewed interest, which seems quite deserved because of their properties; it belongs to the family of special concretes. These characteristics suggest new applications. Lightweight concrete has low density than ordinary concrete and the use of concrete of low density contributes to the reduction of the weight of the elements built with this concrete and subsequently the dimensions of the load-bearing elements, resulting in the reduction of the forces transmitted to the ground by the foundations, and consequently the dimensions of the latter, which allows the construction on soils of low bearing capacity. In this study, we first determined the characteristics of the constituent materials of our lightweight concrete, and then we formulated our lightweight concrete through two distinct formulation methods, namely the Dreux-Gorisse method and the progressive introduction method. Following these formulations, we have made several samples of lightweight concrete. Using laboratory tests, we have determined some of the physical and mechanical characteristics of these lightweight concrete samples. The results showed that when the charcoal content increases in the concrete, its water absorption rate increases. This is accompanied by a decrease of the mechanical strength. The mechanical strength of concrete evolves with time. The tensile strength is about 5 times lower than the compressive strength. The lightweight concretes developed are applicable for masonry bricks production in accordance with SANS 1215, NF DTU 20-1 (1999), NF P 14-304 (1983), NF EN 771-3 (2011) and NF EN 771-3 / CN (2012).
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Keywords:
Lightweight concrete; Cameroonian charcoal; mechanical strength; water absorption rate; formulation.

1 INTRODUCTION

Concrete can be considered no more than a mixture of cement as binder, water, aggregate (fine and coarse) and admixtures (chemicals or minerals or both) [Tchamba 2016], [Neville 2010]. Admixtures are used to improve the performance of the concrete. This could include adjusting setting time or hardening, modifying the properties of the hardened concrete, reducing water required in the concrete, reducing the cost of concrete construction [Ezema 2018]. The concrete usage in France each year is 60 million of m^3 on average of 1 m^3 per capita. Among its constituents, the aggregates occupy up to 75% of concrete volume. Today, concrete remains the manufactured construction material more known and more utilized in the world, whether in the construction of the buildings, bridges, viaducts, airports, roads, railways, tunnels, stadia and other civil engineering infrastructures. Concrete is the second most used substance on earth after water. Its advantages include: high compressive strength, good workability, good durability properties (resistant to freezing, chemical resistant, wear resistant, low permeability, resistant to alkali-aggregate reaction and so on), easy handling and molding, easy transportation from the place of mixing to place of casting before initial set takes place, longevity, resilience and its disadvantages include: low tensile strength, low thermal and acoustics insulation, its heaviness. In order to remedy or mitigate or overcome these weaknesses or disadvantages or limitations of concrete, for example to reduce or decrease its heaviness or its density or its weight and make the buildings lighter, another variety of concrete called lightweight concrete appeared at the beginning of the 20th century in the developed countries of Europe such as France, Germany and the USA and of Asia such as Japan and former USSR [Benkhalfa 1988]. In the field of construction, the reduction of the self-weight of lightweight concrete appears technically and economically interesting, for the restoration of old infrastructures or for the construction of new infrastructures [Benkhalfa 1988]. The reduction of the density of lightweight concrete induces lower dead load to concrete structures, consequently saving on transportation and handling costs. Additionally, the lower density of lightweight concrete exhibits superior heat and thermal insulation, fire resistance as well as reducing risk of earthquake damage [Mo 2017]. According to [Chen 2012], lightweight aggregates today are present in various fields such as the buildings (precast concretes and ready-mixed concrete), public works (as backfilling material). Some are not very resistant even reliable while others are resistant and hard. The search for new lightweight concretes always continues [Neville, 2000], [Fiorio 2004]. A study conducted by [Ke 2006a] informs us that the mechanical characteristics of lightweight concretes strongly depend on the properties and proportions of aggregates present in the formulation. Lightweight concretes are mixtures whose majorities of the constituents are less heavier than the normal concrete [Neville 2000]. The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) lightweight concrete commission quoted by [Hannawi 2011] proposes to define lightweight concretes as concretes with a dry density of less than 1800 Kg/m^3. Other authors adopt a little different definitions: the American Concrete Institute (ACI) limits the bulk density of lightweight concrete to 1800 Kg / m^3 after air drying for 28 days. The German standard, DIN 1042 (1972) limits the apparent density of a lightweight concrete to 2000 kg/m^3. The Eurocode 2 limits the bulk density of lightweight concrete to 2200 Kg/m^3. Compared to conventional concrete whose density lies between 2200 and 2600 Kg/m^3, lightweight concretes have a lower density [Constant 2000]. According to Shink [Shink 2003] and Constant [Constant 2000], the Canadian Portland Cement Association (PCA) defines structural lightweight concrete as having a compressive strength at 28 days higher than 15 MPa whose density is lower than 1850 kg/m^3. The heavy materials found in conventional concrete such as gravels can be replaced by lightweight aggregates as the polystyrene beads, expanded polystyrene [Ouided 2010] for the problems of thermal isolation or acoustics, schist, aggregates of cork [Laoud 2013], [Aziz 1979], ashes of rice balls [Rahman 1988], wood chips [Ledhem 2000], [Tamba 2007], expanded clays and shales, fly ash, pumice, slag, perlite, expanded glass, vermiculite, pumice, oil palm shell, coconut shell, tuff, zeolite, amongst others. So far, no information or data is available from this study area on concrete made with charcoal as lightening aggregate. Within the framework of this work, the density of the concrete represents one of the most important characteristics. The reduction of the density made possible while changing the type of aggregate and while varying the proportions of the various constituents is the principal stake of this study. This article proposes the formulation and characterization of lightweight concrete impregnated with cement and Cameroonian charcoal as lightweight aggregate obtained from the eucalyptus plant in North West Region, Bamenda, Cameroon.

2 EXPERIMENTAL DETAILS

The experimental investigation for this study aims to control the formulation and characterization of lightweight concretes impregnated with cement and Cameroonian charcoal. It relied on the characteristics of the cement matrix and the percentage of lightweight aggregates as well as the water/cement ratio, which will be varied to affect the rheological and mechanical characteristics of lightweight aggregate concretes (LWAC).

The materials used in this study are from local sources (Cameroon) because of their abundant availability and moderate cost.

2.1 Materials

2.1.1 Ciment

The cement used in the lightweight concretes production was the ROBUST. It was supplied by the DANGOTE cement plant at Bonaberi in Douala (Cameroon). It is a Portland cement with pozzolana or limestone, its normative name is the CN CEM II/B-P 42.5 R. It is a 42.5R grade Rapid Hardening Cement with an initial setting time ≥ 60 minutes.

Chemical and mineralogical compositions in accordance with the Cameroonian standard (NC 234: 2009-06) are summarized in Tab. 2 and 3, respectively. Tab. 1 reports physical and mechanical characteristics.

Tab. 1: Physical and mechanical characteristics of Portland cement (NC CEM II/ B-P 42,5R) used

Characteristics	NC CEM II/ B-P 42.5 R
Apparent density(g/cm^3)	Not specified
Absolute density (g/cm^3)	Not specified
Fineness (cm²/g)	3900-4000
Initial setting time (min)	≥ 60
Expansion- (Soundness) (mm)	≤10
Compressive strength at 2 days (MPa)	≥20
Compressive strength at 28 days (MPa)	≥ 42.5 ≤ 62.5

Tab. 2: Chemical composition of Portland cement (NC CEM II/ B-P 42,5R) used

Chemical composition (%) : NC CEM II/ B-P 42,5R	
MgO	≤ 5.0
SO_3	≤ 3.5
Cl	≤ 0.02

Tab. 3: Mineralogical composition of Portland cement (NC CEM II/ B-P 42,5R) used

Mineralogical composition of Portland cement (%) : NC CEM II/ B-P 42,5R	
Main constituents	(%)
Clinker	65-79
Secondary constituents	(%)
Pozzolana	21-35
Gypsum	≤ 5%

2.1.2 Sand

2.1.2.1 Particle size analysis

The rolled sand studied is extracted from the river Sanaga (Ebebda-Cameroon). The rolled sands are alluviums that come from the river beds. They result from the segregation of granite rocks and are transported by water or wind erosion to the beds of the rivers where they deposit as sediment. The sand used is granular class 0/5. The particle size analysis was performed using seven sieves of diameter: 5 mm, 2.5 mm, 1.25 mm, 0.63 mm, 0.315 mm, 0.16 mm and 0.08 mm.

The results (Fig. 1) of the particle size analysis by sieving method conform to NF P 18-101, show that D10 = 0.15 mm, D30 = 0.48mm and D60 = 1.2 mm.

From the grading curve, the values of D_{10}, D_{30} and D_{60} enable us to calculate the coefficient of uniformity of HAZEN (C_U) and the coefficient of curvature (Cc), we have:

D_{10}= 0.15mm; D_{30}= 0.48mm and D_{60}= 1.2mm.

And :

$$C_u = \frac{D_{60\%}}{D_{10\%}} = \frac{1.2}{0.15} = 8, \qquad C_u = 8$$

Also:

$$C_C = \frac{(D_{30\%})^2}{D_{10\%} \times D_{60\%}} = \frac{(0.48)^2}{0.15 \times 1.2} = 1.28\,, \qquad C_C = 1.28$$

$1<C_c<3$ and $C_U > 4$ thus, we have a well graded sand.

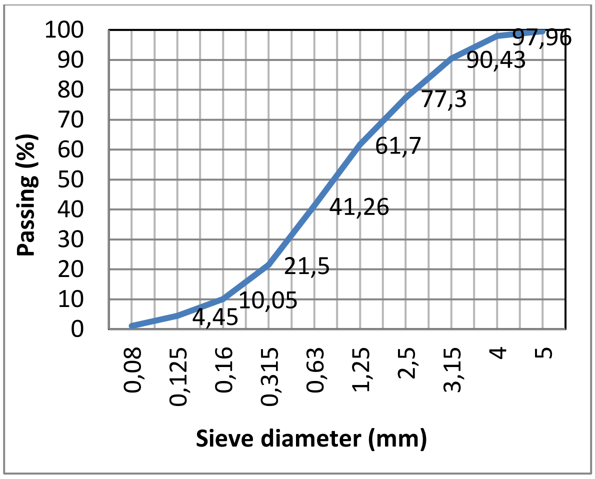


Fig. 1: Particle size distribution curve of sand 0/5 used

2.1.2.2 Sand equivalent test

This test was conducted according to NF P 18-598 with class 0/5 Sand. The sand equivalent test was done on three sand samples and the final result is the average of individual results. Two kinds of testing were performed, the visual sand equivalent (SE) and sand equivalent (SEP) from piston tests. The overall result is the average of visual sand equivalent and sand equivalent from piston which is SE = 86.56 >80% and thus the sand is very clean, almost total absence of fine clay, which does not risk causing a lack of plasticity in the concrete.

Tab. 4: Physico-chemical characteristics of the sand sample

Characteristics	Sand 0/5
Fineness modulus	2.68
Absolute density (t/m^3)	2.597
Apparent density	Not specified

Based on the characteristics obtained in Tab. 4 above, we observe that the Sanaga sand is justified for our study. XP P 18-540 specifies that for a value of the fineness modulus between 2.2 and 2.8, we have a good concrete sand that offers good workability and good resistance. On the other hand, according to Dreux and Gorisse (1969), the good sand must have a fineness modulus around 2.5.

2.1.2.3 Density

The absolute density was measured using a pycnometer. Table 4 shows the average of individual results. The results obtained from 03 sand samples show that, from one measure to another, the density of the sand is not very different.

2.1.3 Water

Water is an asymmetrical material consisting of an oxygen atom and two hydrogen atoms. It intervenes by its mechanical and physico-chemical properties at all stages of the life of the concrete, it ensures the hydration of the cement, confers its plasticity and allows its flow at fresh state. The mixing water is rarely encountered in its pure state. It contains ions in solution and solid particles in suspension, the salts in low proportion dissolved in this water are involved in the rheology of cementitious matrix materials.

The water used in the manufacturing of concrete does not contain harmful elements and impurities in such quantities that they could adversely affect the setting, hardening and durability of the concrete. The amount of water is a function of the nature of the binder used, the prior humidity of the lightweight aggregates, and the use of the concrete. We assume that it meets all of the requirements of the standard (EN 1008) for the regulation of mixing water for concrete and does not require testing.

Clean water for mixing lightweight concretes was obtained from public water system (Camwater).

2.1.4 Charcoal

The quality of lightweight aggregates is an important parameter for the manufacture of lightweight concretes. For this work, charcoal used in lightweight concrete is produced from eucalyptus plant (Fig. 2) in North West Region, Bamenda, Cameroon.

Fig. 2: eucalyptus plant in Bamenda.
(http://infocongo.org/fr/cameroun-leucalyptus-tresor-controverse-des-grassfields/)

It is a type of wood that is more or less suitable for the manufacture of coal because of its density and the energy available during combustion. Charcoal was characterized by the following physical properties:

- Particle size analysis

The granular fraction of the coal used for our tests is 05/20. The particle size analysis is performed in accordance with the standard (not specified). Figure 3 shows the particle size distribution curve.

- Absorption rate

The absorption rate test was performed on three (03) samples of charcoal. The results showed that the absorption rate of the charcoal used is 73.04% (average of individual results).

- Absolute density

The absolute density was measured using a pycnometer. The results obtained from 03 charcoal samples show that, from one measure to another, the density of the charcoal is not very different. The results also showed that the absolute density of the charcoal used is 0.57t/m^3 (average of individual results).

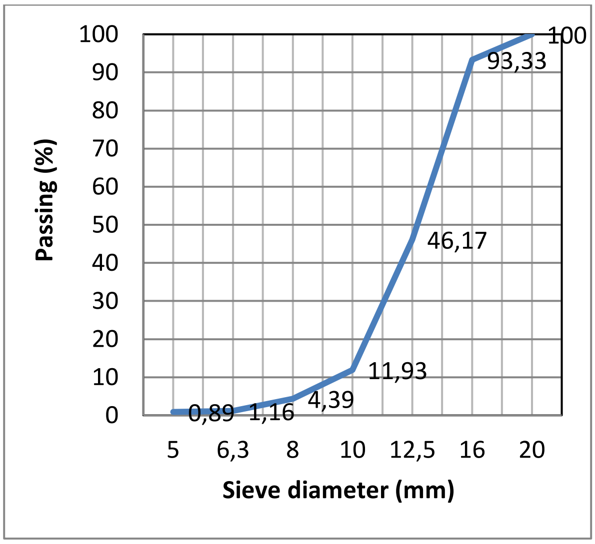


Fig. 3: Particle size distribution curve of charcoal 5/20 used

3 COMPOSITION OF LIGHTWEIGHT CONCRETES

Our experimental programme aims to contribute to the upgrading of charcoal aggregates by incorporating them into a cementitious matrix, for the development of a composite based on charcoal particles. This study examines the behaviour of a mortar in which sand has been substituted by charcoal aggregates. The classical methods of formulation of concretes are difficult to apply to lightweight concretes impregnated with charcoal given the hydrophilic character of the aggregates used. Previous work on the subject uses methods of arbitrary formulations and disseminated in the form of trial and error [Constant 2000]. Two methods were chosen for the composition of the material studied in this work. The specimens were made with different formulations to better understand the influence of the formulation on the properties of the concrete sought.

3.1 Dreux-Gorisse formulation method

a) Justification for the choice of the formulation method:

Since particle size and in particular absolute density are two parameters that vary considerably depending on the type of coal used, we have chosen to apply the Dreux-Gorisse formulation method. Particular importance is given to the particle size and absolute density of the aggregates of our lightweight concretes. The objective is to determine according to the criteria of workability, expected strength, the nature and quantities of materials required to manufacture a cubic metre of concrete (Water (W), Cement (C), Sand (S), Charcoal (Ch)) in Kg/m³).

Depending on the type of work to be performed, the parameters necessary for concrete implementation and for the short and long term stability of the structure must be defined. The main parameters to be defined are: the workability, the expected strength of the concrete, the nature of the cement and the type of aggregates. The different proportions of concrete samples used are shown in Tab. 5 below.

Tab.5: Mixture proportions for concrete samples (1m^3)

Quantity in Kg	Cement (C)	Sand(S)	Charcoal (Ch)	Water (W)
Sample A	267	986.34	211.40	186.86
Sample B	289.28	963.56	206.52	202.39
Sample C	314.28	939.61	201.38	219.88
Sample D	342.21	914.42	195.99	239.31

3.2 Progressive formulation method

This method is based on a choice of a cementitious matrix that assigns a desired lightweight concrete, it is called M0, that is, the percentage of the lightweight aggregate is zero (control). For our mixtures, the search for a compromise resistance-workability led us to choose 5 compositions of lightweight charcoal concretes (LWCC) to test them. In this method, the sand will be progressively replaced by charcoal aggregates with a density of g = 25%, then 50%, 75% and finally 100% by volume of natural units by the additional volume of artificial assemblies. The cement and water dosage will remain constant. The choice of this method is justified by the fact that it will allow us to highlight the influence of charcoal in concrete. The different compositions used are shown in Tab. 6 below.

Tab. 6: Compositions of the different mixtures.

Constituents (Kg/m^3)	M0	M25	M50	M75	M100
Charcoal	0	337.5	675	.012.5	1350
Sand	1350	1012.5	675	337.5	0
Cement	450	450	450	450	450
Water	225	225	225	225	225
g (%)	0%	20%	50%	75%	100%
W/C	0.5	0.5	0.5	0.5	0.5

3.3. Mixes design and specimens preparation

Lightweight concretes are made like normal concretes but with lightweight aggregates. The mixture proportions and components for the Dreux-Gorisse formulation and progressive formulation method are shown in Tab. 5 and Tab. 6, respectively. The mixing sequence of the constituent materials was as follows: Charcoal was mixed with cement for four minutes to homogenize the mixture and then extended for another four minutes after the sand has been incorporated. The mixing water is then added, and the mixing is continued for four minutes. The mixing was done correctly to obtain a homogeneous mixture with uniform properties [Tchamba 2008].

4 TESTING METHODS

The samples of lightweight concretes made with different formulations were subjected to the following tests:

4.1 Water Absorption

The water absorption tests were conducted to measure the water absorption properties of the lightweight concrete specimens. The equipment included the bucket, clean water, a balance and a stop watch. The test consisted of determining the amount of water absorbed by the lightweight concrete specimens for 24 hours. The samples after demolding were oven dried for 48 hours, they then be weighed (W_1), then immersed in water for 24 hours and weighed again (W_2). The percentage of water absorption (A) was computed for each sample using Equation 1.

$$A\,(\%) = \frac{W_2 - W_1}{W_2} \times 100 \quad (1)$$

Where: W_1 = weight of lightweight concrete before immersion, W_2 = weight of lightweight concrete after immersion.

4.2 Compressive strength

The compression test was used to determine the compressive strength of the lightweight concretes, as well as describe the behavior of the lightweight concretes when subjected to compressive load. The equipment included the compression machine and metallic plates to surmount the compressive plates. The lightweight concrete specimens at 7, 14 and 28 days of maturity were mounted on to the compression machine (Fig. 4) and the compressive load was increased at 0.05mm/S until the lightweight concrete fractured. The compressive strengths of the lightweight concretes were calculated using Equation 2.

$$\boldsymbol{\sigma} = F/S \quad (2)$$

Where: $\boldsymbol{\sigma}$ = compressive strength, F = maximum load applied before failure, S = cross sectional area of the specimen.

Fig. 4: Compressive strength testing machine

4.3 Tensile strength

As we all know, concrete is strong in compression and weak in tension. In other words, the tensile strength of the concrete is very low, but it is important to know its value. Compared to the compressive behavior of concrete, the tensile behavior has received a little attention in the past, partly because it is a common practice to ignore tensile strength in reinforced concrete design [Kitouni 2013]. Interest in tensile properties has grown substantially in recent years partially due to introduction of fracture mechanics into the field of concrete structures [Kitouni 2013].

We had deduced the value of the tensile strength by using Equation 3.

$$Ftj = 0.6 + 0.06fcj \quad (3)$$

If fcj less than 40 MPa. Where fcj = compressive strength at j day.

5 RESULTS AND DISCUSSION

Figure 5 show the variation of the rate of water absorption of the lightweight concrete as a function of its density using Dreux-Gorisse formulation method. It can be seen that when the lightweight concrete density decreases, its water absorption rate decreases. The average rate of water absorption is approximately 30%. So the denser the lightweight concrete, the more it will absorb water.

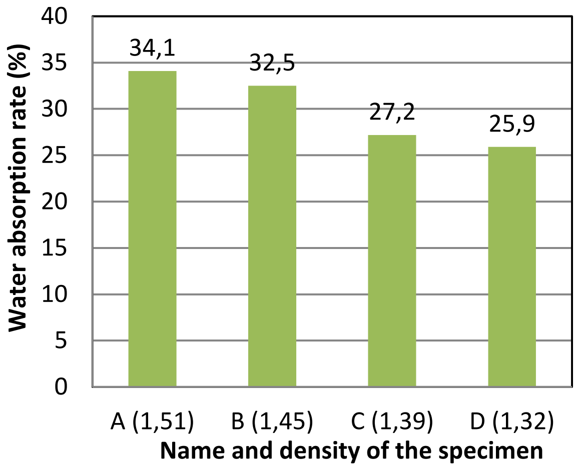


Fig. 5: Variation of the rate of water absorption of the concrete as a function of its density

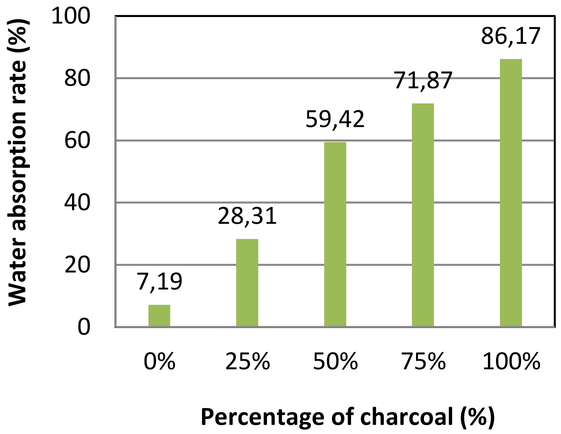
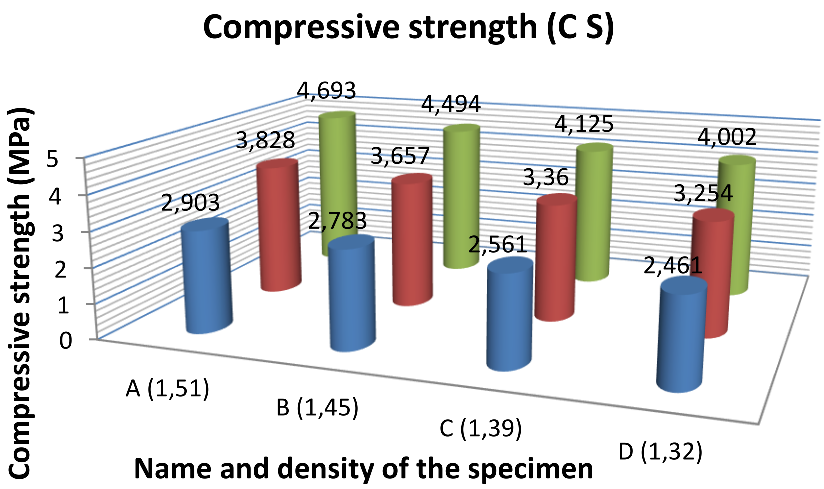


Fig. 6: Water absorption rate of concrete as a function of charcoal content

The results of the water absorption using the progressive formulation method are shown in Fig. 6. The coefficient of water absorption increases as the percentage of charcoal increases in the mix. So the more the concrete is rich in charcoal, the more it absorbs water. This can be explained by the fact that charcoal is a porous material. Sample of 0% (control) replacement had a lower water absorption compared to samples of 25%, 50%, 75%, and 100% replacement.

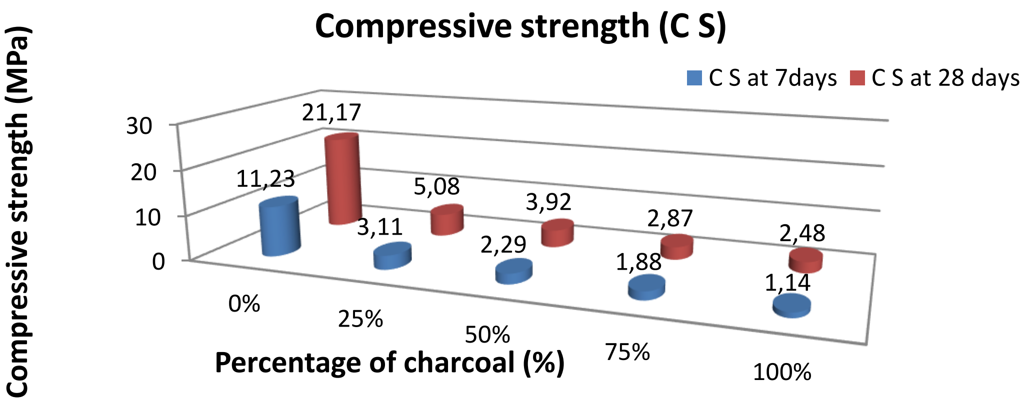
The results of the compressive strength tests are shown in Fig. 7. The diagram shows the compressive strength with respect to the density and curing time using Dreux-Gorisse formulation method. The American Concrete Institute (ACI) limits the bulk density of lightweight concrete to 1800 Kg /m^3 after air drying for 28 days. From Figure 7, it can be seen that all mixes are within the range for structural lightweight concrete. The density ranging from 1.32 t/m^3 to 1.51 t/m^3 or from 1320 Kg/m^3 to 1510 Kg/m^3. The compressive strength decreased with the reduction of the density of lightweight concrete. The compressive strength also increased as the curing time increased.



	A (1,51)	B (1,45)	C (1,39)	D (1,32)
C S at 7days	2,903	2,783	2,561	2,461
C S at 14 days	3,828	3,657	3,36	3,254
C S at 28 days	4,693	4,494	4,125	4,002

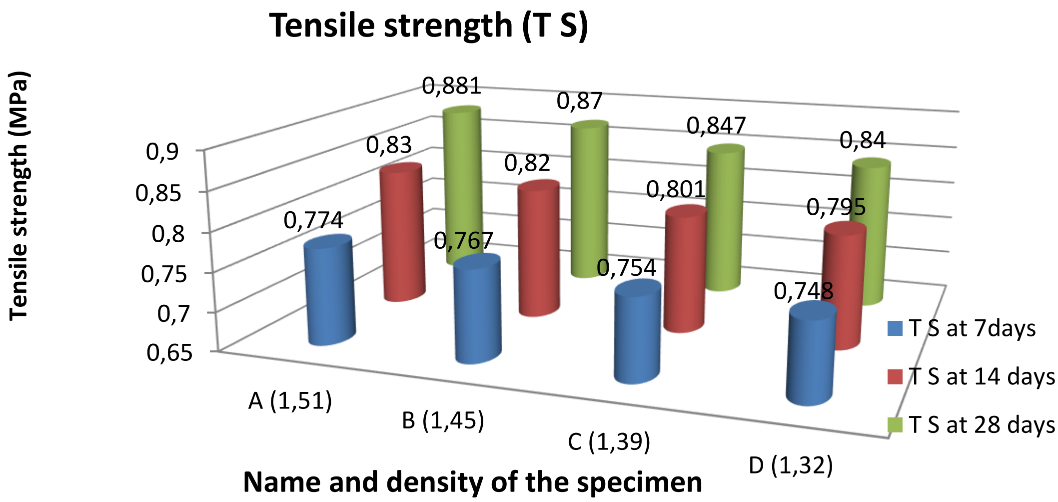
Fig. 7 : Compressive strength of concrete as a function of time and density.

The variations of compressive strength of the control specimens and other specimens containing charcoal using the progressive formulation method are shown in Fig. 8. Samples of 0% replacement (control) had a greater compressive strength at each age compared to samples of 25%, 50%, 75%, and 100%. The optimum compressive strength was obtained at 25% of charcoal replacement. The minimum compressive strength required for masonry units or bricks as stipulated by the South African standard (SANS 1215) is 3.0 MPa and from 25 to 50% charcoal replacement give compressive strength between 3.92 and 5.08 MPa at 28 days of maturity, thus adequate for masonry applications. On the other hand, according to the French standards NF DTU 20-1 (1999), NF P 14-304 (1983), NF EN 771-3 (2011) and NF EN 771-3 / CN (2012), the compressive strength greater than the value of 2.5 MPa is required for the manufacture of lightweight aggregates concrete hollow blocks to be used to build non-load-bearing walls and partitions of buildings. Also, Spence [Spence 1983] suggested an average brick strength ranging from 3.0 to 3.5 MPa for load bearing requirements of normal two-story buildings. The presence of charcoal poses problems of resistance, resulting in a decrease of the mechanical strength of the concrete. This is consistent with the literature on lightweight concrete, which notes that lightweight concretes are less resistant than conventional concretes. The decrease of the mechanical strength of concrete is probably due to the fact that charcoal, because of its low density and fragility, always tends to crumble, even under low stress. Thus, the strength of the concrete is relatively low. The evolutions of the resistances as a function of time show that at the beginning, the resistances decrease for all samples. Whereas the following periods, the resistances increase significantly. This is due to the kinetics of the cement hydration reaction.



	0%	25%	50%	75%	100%
C S at 7days	11,23	3,11	2,29	1,88	1,14
C S at 28 days	21,17	5,08	3,92	2,87	2,48

Fig. 8: Compressive strength of concrete as a function of time and charcoal content.

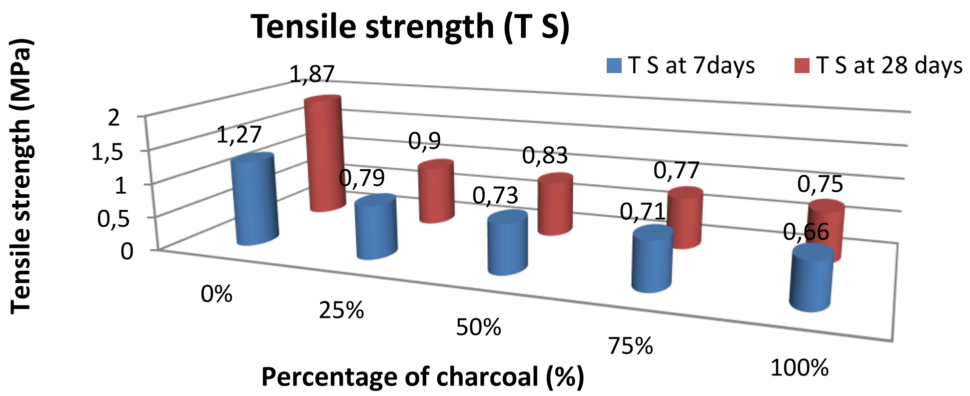


	A (1,51)	B (1,45)	C (1,39)	D (1,32)
T S at 7days	0,774	0,767	0,754	0,748
T S at 14 days	0,83	0,82	0,801	0,795
T S at 28 days	0,881	0,87	0,847	0,84

Fig. 9 : Tensile strength of concrete as a function of time and density.

The variations of tensile strength with respect to the density and curing time using Dreux-Gorisse formulation method are shown in Fig. 9. The tensile strength decreased with the reduction of the density of lightweight concrete. The tensile strength also increased as the curing time increased.

The variations of tensile strength of the control specimens and other specimens containing charcoal using the progressive formulation method are shown in Fig.10. Samples of 0% replacement (control) had a greater tensile strength at each age compared to samples of 25%, 50%, 75%, and 100%. The optimum tensile strength was obtained at 25% of charcoal replacement. The tensile strength evolves in a manner similar to that of compressive strength. The tensile strength is about 5 times lower than the compressive strength.



	0%	25%	50%	75%	100%
T S at 7days	1,27	0,79	0,73	0,71	0,66
T S at 28 days	1,87	0,9	0,83	0,77	0,75

Fig. 10: Tensile strength of concrete as a function of time and charcoal content.

6 CONCLUSION

This paper presents the lightweight concrete made with Cameroonian Charcoal as coarse lightweight aggregate and reports the absorption and mechanical performance of this kind of concrete.

Although lightweight concrete has been known around the world for over a quarter of a century, they are not employed yet in Cameroon. The possibility of substituting the natural aggregates in the normal concretes was explored. Based on the results obtained, the following conclusions were drawn:

- The water absorption of the charcoal used is 73.04%.

- The absolute density of the charcoal used is 0.57 t/m^3.

- The particle size distribution curve of the sand used showed that we have a continuously graded sand with a fineness modulus of 2.68.

- The absolute density of sand used is 2.6 t/m^3.

- When the charcoal content increases in the concrete, its mechanical resistance decreases.

- The tensile strength is about 5 times lower than the compressive strength.

-The lightweight concretes developed are applicable for masonry bricks production.

- When the charcoal content increases in the concrete, its water absorption rate also increases.

- The mechanical resistance to compression increases with the curing time and the evolution from one formulation to another is rather similar.

7 REFERENCES

[Aziz 1979] Aziz, M.A.; Murphy, C.K.; Ramaswamy S.D.; Lightweight concrete using cork granules, International Journal of Cement and Composites and Lightweight Concretes; Volume 1. Issue 1, October 1979, Pages 29-33.

[Benkhalfa 1988] Benkhalfa, B.; contribution a l'étude des bétons légers d'argile expansée pour des éléments armés préfabriqués. Thèse de magistère, Université d'Annaba, 1988.

[Chen 2012] Chen, H. J.; Yang, M. D.; Tang, C. W.; Wang, S. Y.; Producing synthetic lightweight aggregates from reservoir sediments, Construction and Building Materials, 28 (2012), pp. 387-394.

[Constant 2000] Constant, M.; Confection de bétons légers, la fabrication d'éléments architecturaux, Projet d'application présenté à L'école de technologie supérieure, Ecole de technologie supérieure, Université du Québec, Édition. Montréal, 14 Avril 2000.

[Dreux 1964] Dreux, G.; Contribution à l'étude de l'influence de la propriété du sable sur diverses qualités du béton, annales I. T. B. T. P. n° 198. 37 p. 1964.

[Dreux 1969] Dreux, G.; Gorisse, F.; Contribution à l'étude de la finesse des sables sur diverses qualités des bétons, annals, I. T. B. T. P. n° 261. 41 p. 1969.

[Ezema 2018] Ezema, I.C.; Olatunji, O.; Building Collapse in Lagos State, Nigeria: Towards Quality Control in Materials, Batching and Placement of Concrete, Covenant Journal of Research in the Built Environment (CJRBE), 2018, Vol. 6, No. 1,pp.25-39.

[Fiorio 2004] Fiorio, B.; Beaucour, A.L.; Ortola, S.; Optimization of the Mechanical Behavior of Lightweight Aggregate Concrete by the use of High Performances Cementitious Matrixes, Symposium Fib (ceb – fip) / AFGC on Concrete Structures: the Challenge of Creativity, Avignon, France, April, 26-28, 2004.

[Hannawi 2011] Hannawi, K.; Conception, Caractérisation physico-mécanique et durabilité de nouveaux matériaux de construction à caractère environnemental, INSA Rennes, France, 2011.

[Ke 2006a] Ke, Y.; Beaucour, A. L.; Ortola, S.; Dumontet, H.; Cabrillac, R.;Comportement mécanique des bétons de granulats légers ; étude expérimentale et modélisation, In XXIVéme Rencontres du Génie Civil et Urbain, Construire: les nouveaux défis, 2006a.

[Kitouni 2013] Kitouni, S.; Houari, H.; Lightweight concrete with Algerian limestone dust. Part I: Study on 30% replacement to normal aggregate at early age, Cerâmica 59 (2013) 600-608.

[Laoud 2013] Laoud, B.; Caractérisation mécanique et physique d'un béton léger à base de sable calcaire et des granulats de liège, International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol. 3 No. 3 July 2013, pp. 739-748.

[Ledhem 2000] A Ledhem, R.M. Dheily, M. L. Benmalek, M. Queneudec « Properties of wood-based composites formulated with aggregate industry waste, Construction and Building Materials, Volume 14, Issues 6-7, September–October 2000, pp.341-350.

[Mo 2017] Mo, K.H.; Ling, T.C.; Alengaram, U.J.; Yap, S.P.; Yuen, C.W.; Overview of supplementary cementitious materials usage in lightweight aggregate concrete, Construction and Building Materials, 139, 2017, 403–418.

[Neville 2000] Neville, A.; Propriétés des bétons. Eyrolles. Paris, 2000.

[Neville 2010] Neville, A. M.; Brooks, J. J.; Concrete Technology (2nd ed.). Longman Group, UK publishers Ltd, 2010.

[Ouided 2010] Ouided, H.; Formulation et Caractérisation des Bétons Légers. Thèse de magistère. Université Mohamed Khider – biskra. 2010.

[Rahman 1988] Rahman, M.A.; Effect of rice husk ash on the properties of bricks made from fired lateritic soil-clay mix, Materials and Structures, May 1988, Volume 21, Issue 3, pp 222–227.

[Salas 1986] Salas, J.; Alvarez, M.; Veras, J.; Lightweight insulating concretes with rice husk, International Journal of Cement Composites and Lightweight Concrete, 8:171-180,1986,Volume 8. Issue 3, August 1986, Pages 171-180.

[Shink 2003] Shink, M.; Compatibilité élastique, comportement mécanique et optimisation des bétons de granulats légers, Université Laval, Québec, Canada, Avril 2003.

[Spence 1983] Spence, R. J. S.; Cook, D. J. ; Building Materials in Developing Countries, John Wiley and Sons, 1983, Chichester, England.

[Tamba 2007] Tamba, S.; Voumbo, L.M.; Wereme, A.; Gaye, S.; Sissoko, G.; Durabilité des bétons légers à base de copeaux de bois, J. Sci. 7 (2007) 67–72.

[Tchamba 2008] Tchamba, J. C.; Contribution à l'étude expérimentale du comportement des matériaux cimentaires au jeune âge: pression; rhéologie et perméabilité. (PhD thesis), Université de Bretagne Sud, Lorient, France, 2008.

[Tchamba 2016] Tchamba, J.C.; Bikoko, T.G.L.J.; Failure and Collapse of Building Structures in the Cities of Yaoundé and Douala, Cameroon from 2010 to 2014, Modern Applied Science, 2016, Vol. 10, No. 1, pp. 23-33.

NF EN 1008 Juillet 2003. Indice de classement 18-211. Norme européenne de l'eau de gâchage pour bétons, specifications d'échantillonnage, d'essais et d'évaluation de l'aptitude à l'emploi (juillet 2003).

NF XP P 18-540: Granulats-Definition, conformité, specification. Octobre 1997.

NF P 18-598: Granulats-Equivalent de sable. Octobre 1991.

NF P 18-101: Analyse granulometrique-Web GRR NF P 08 501

NF P 18-560 : Granulats - Analyse granulométrique par tamisage, AFNOR Paris (1990).

NF DTU 20-1 (1999), Building works-Masonry structures for small elements-Walls and walls-Part 2: Design rules and minimum construction requirements-Addendum 2 to the P10-202-2 standard of April 1994. AFNOR, Paris.

NF P 14-304 (1983): Agglomerates - Concrete blocks of light aggregates for walls and partitions. AFNOR, Paris.

NF EN 771-3 (2011). Specification for masonry units - Part 3: Concrete masonry aggregates (common and light aggregates). AFNOR, Paris.

NF EN 771-3 / CN (2012). Specification for masonry units - Part 3: Concrete masonry aggregates elements (common and light aggregates) - National supplement to NF EN 771-3: 2011. AFNOR, Paris.

The European Union per Regulation 305/2011; Directive 98/34/EC, D. 2004/18/EC Eurocode 2: Design of Concrete Structures. Part 1-1: General Rules and Rules for Buildings. Section 11: Lightweight Aggregated Concrete Structures; European Union: Brussels, Belgium, 2010.

South African National Standards, SANS 1215 - Concrete Masonry Units, Standards South Africa, Pretoria, 2008.

http://infocongo.org/fr/cameroun-leucalyptus-tresor-controverse-des-grassfields/).