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CHARACTERIZATION OF LIGHTWEIGHT CONCRETE IMPREGNATED WITH CEMENT AND CAMEROONIAN CHARCOAL AS COARSE LIGHTWEIGHT AGGREGATE

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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 coarse 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 conventional 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 concretes, and then we formulated our lightweight concretes 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 concretes. 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)

Key words: Lightweight concrete, Cameroonian charcoal, mechanical strength, water absorption rate and formulation.

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1. INTRODUCTION

Concrete can be considered no more than a mixture of cement as a binder, water, aggregate (fine and coarse) and admixtures (chemicals or minerals or both) [1,2]. 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 [3]. The concrete usage in France each year is 60 million of m³ on average of 1 m³ 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-silica 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, former USSR and other countries [4]. 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 [4]. 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 [5]. According to [6], lightweight aggregates today are present in various fields such as the buildings (precast concretes and ready-mixed concrete), public works (as backfilling materials). Some are not very resistant even reliable while others are resistant and hard. The search for new lightweight concretes always continues [7, 8]. A study conducted by [9] 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 [7]. The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) lightweight concrete commission quoted by [10] 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 [11]. Compared to conventional concrete whose density lies between 2200 and 2600 Kg/m^3 , lightweight concretes have a lower density [12]. 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 [12,13]. The heavy materials found in conventional concrete such as gravels can be replaced by lightweight aggregates as the polystyrene beads, expanded polystyrene [14] for the problems of thermal isolation or acoustics, schist, aggregates of cork [15,16], ashes of rice balls [17], wood chips [18,19], expanded clays and shales, fly ash, pumice, slag, perlite, expanded glass, vermiculite, pumice, oil palm shell, coconut shell, tuff, zeolite, scoria, volcanic cinders, vesiculated lava, amongst others. So far, no information or data is available from this study area on concrete made with charcoal as coarse lightweight 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 coarse lightweight aggregate obtained from the eucalyptus plant in North West Region, Bamenda, Cameroon.

2. LITERATURE REVIEW

The first lightweight concretes have been made with Grecian and Italian pumice as the lightweight aggregates. Hydrated lime was used as a binding material. Studies related to lightweight concrete have been conducted since the beginning of the 20th century and in 1923, Mr. Dan Servey manufactured the first lightweight concrete masonry units.

Kitouni and Houari [20] studied the physical performance of concrete formulated with substitution of 30% of coarse aggregates by Algerian limestone dust. The study involved preparation of lightweight concrete based on CEM II/ A (CPJ 42.5), sand and crushed gravel of class 0/3 mm and 3/8 mm, respectively, limestone dust, tap water and plasticizer. The chemical composition of CEM II/ A (CPJ 42.5) and the formulation of concrete used are given in Table 1 and Table 2, respectively. The performance properties investigated were: Young modulus, compressive and flexural tensile strength. The Poisson's ratio and mass loss at different ages were also carried out. The results showed that the lightweight concretes developed meet the requirements for a construction material to be used in the structural

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applications with compressive strength and flexural tensile strength reaching 34.99 MPa and 6.39 MPa, respectively.

Table 1 Chemical composition (%) of CEM II/ A (CPJ 42.5) [20].

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	Chlorides	Free CaO	Insoluble	Loss on ignition
27.83	6.21	3.12	57.22	0.94	2.02	/	/	0.00	0.88	2.28	2.41

Table 2 Formulation of concrete for 1 m³ [20].

Materials used	Amount	Unit
Cement (C)	350.00	Kg
Water (W)	199.00	L
W/C	0.56	/
Sand	691.60	Kg
Granular (3-8)	726.18	Kg
Limestone dust (20i)	311.22	Kg
Superplasticizer	10.50	L

Sobuz et al. [21] reported an experimental study on the strength characteristics and cost analysis of concrete using different proportions of palm shells as substitutes for conventional coarse aggregate. The study involved collecting the oil palm shells (OPS), the coarse aggregate from igneous origin, fine aggregate from River sand, Malaysian ordinary Portland cement conforming to ASTM type I and water from the laboratory stand post. The characteristics of OPS and crushed granite aggregate used are reported in Table 3. The preparations of the samples were conducted as followed: Firstly, sand and cement were properly mixed with trowel and then OPS and crushed stones were added, then water was added at different interval after the cement. All the component materials were mixed together with the help of shovel. Concrete cubes and cylinders were casted. Fresh concrete workability, compressive strength, flexural strength, splitting tensile strength tests, among others at 7 and 28 days were investigated. Based on test results, the authors outlined that the compressive and flexural strength of concrete decreased as the percentage of OPS increased in the mix proportions. They concluded that OPS have the potential to be used as substitute coarse aggregate in the production of low-cost lightweight concrete.

Table 3 Properties of OPS and crushed stone aggregate [21].

Properties	Palm shell aggregate	Crushed stone aggregate
Specific gravity	1.21	2.72
Bulk density (Kg/m ³)	572	1445
Los Angles abrasion value, %	5.1	24.5
Water absorption for 24 h (%)	25.64	0.7
Aggregate crushing value	6.78	17.92
Aggregate impact value	6.65	12.32
Fineness modulus	6.24	6.76
Shell thickness, mm	0.5–4.0	5–20
Maximum aggregate size, mm	12.5	20

Solak et al. [22] studied the effects of supplementary cementitious materials namely, silica fume (SF), fly Ash (FA) and posidonia oceanica Ash (PA) on workability and segregation resistance of lightweight aggregate concrete. Their powder X-ray diffraction (XRD) and

chemical composition are shown in Figure 1 and Table 4, respectively. The mixtures proportions used to produce the concrete and mortar samples are shown in Table 5 and 6, respectively. Three different percentage substitutions of cement namely 5%, 10% and 15% by weight were used. They reported that adding silica fume resulted in a reduction of the workability and slightly reduction of the density of the lightweight aggregate concretes (LWAC). Fly ash improved the workability of the concrete and almost did not affect the density of the mortar matrix. Adding Posidonia ash resulted in a reduction of the workability of the LWAC. High levels of substitution of cement by fly ash could lead to segregation of the aggregates.

Table 4 Chemical characteristics of SF, FA and PA [22].

Component	SF	FA	PA
Na ₂ O	0.30	-	0.62
MgO	0.91	1.43	11.24
Al ₂ O ₃	0.30	23.89	0.88
SiO ₂	88.53	39.68	10.20
P ₂ O ₅	0.14	0.42	0.50
SO ₃	0.42	0.45	6.04
Cl ⁻	-	-	0.57
K ₂ O	0.51	1.18	0.07
CaO	2.81	4.38	49.59
TiO ₂	0.10	1.02	0.18
Fe ₂ O ₃	0.21	11.39	1.58
S _p O	-	0.13	-
CuO	-	-	0.04
S _r O	0.03	-	0.32
BaO	0.58	0.90	0.51
WO ₃	0.21	0.34	0.15
L.O.I ¹	4.95	14.79	17.52

¹Loss on ignition

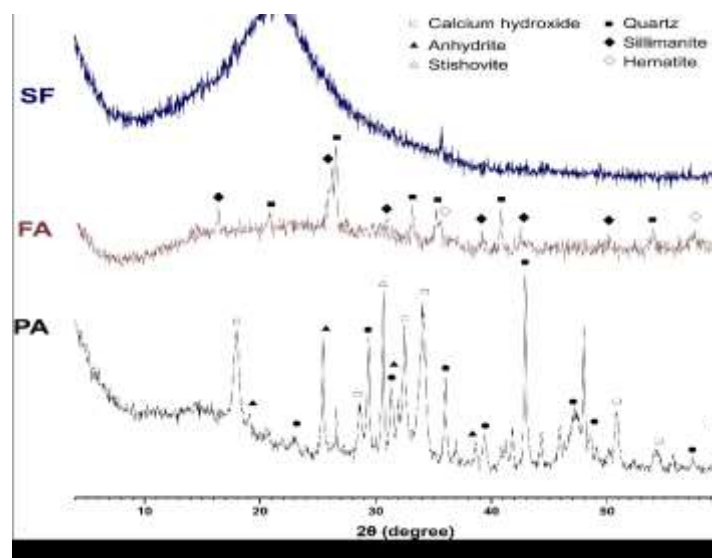


Figure 1 XRD patterns of SF (silica fume), FA (fly ash) and PA (Posidonia oceanica ash) [22].

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Table 5 Mixtures proportions used to produce 1 m³ of concrete [22].

Concrete	Type of SCM	Water (kg/m ³)	Cement (kg/m ³)	SCM (kg/m ³)	LWA (kg/m ³)	Sand (kg/m ³)
Control	-	243	347	0	109	1100
SF5	SF	243	330	17	106	1104
SF10	SF	243	312	35	102	1107
SF15	SF	243	295	52	98	1111
FA5	FA	243	330	17	109	1101
FA10	FA	243	312	35	108	1102
FA15	FA	243	295	52	107	1103
PO5	PO	243	330	17	109	1100
PO10	PO	243	312	35	109	1100
PO15	PO	243	295	52	108	1100

Table 6 Mixtures proportions used to produce 1 m³ of mortar [22].

Concrete	Type of SCM	Water (kg/m ³)	Cement (kg/m ³)	SCM (kg/m ³)	Sand (kg/m ³)
Control	-	218	347	0	1100
SF5	SF	219	330	17	1104
SF10	SF	219	313	35	1107
SF15	SF	220	295	52	1111
FA5	FA	218	330	17	1101
FA10	FA	218	313	35	1102
FA15	FA	218	295	52	1103
PO5	PO	218	330	17	1100
PO10	PO	218	313	35	1100
PO15	PO	218	295	52	1100

In 2017, Muralitharan and Ramasamy [23] developed a lightweight concrete in the laboratory using pumice stone as lightweight aggregate and report the performance of this kind of concrete under slow cycling loading. Their study revealed that the average ultimate load of control and lightweight concrete beams of three each were 40.13 KN and 34.51 KN, respectively. The percentage reduction in load for lightweight concrete beam is 14 compared to control beams. The average energy absorption of control and lightweight beam of three each are 706.07 KN mm and 305.21 KN mm, respectively. The percentage reduction on load for lightweight beam is 56.77 compared to control beams. The average stiffness degradation of control beam and lightweight concrete beam were 1.46 KN/mm and 1.137 KN/mm, respectively.

Nadesan and Dinakar [24] proposed a mix design methodology for the development of sintered fly ash lightweight aggregate concretes (SLWAC) and evaluated the performance of these concretes via proper experimental investigations. The flow chart of the methodology is shown in Figure 2. It was found that the proposed method is simple and reliable for the design of lightweight concrete using sintered fly ash lightweight aggregates for strengths up to 70 MPa and can be used by field engineers at the construction sites.

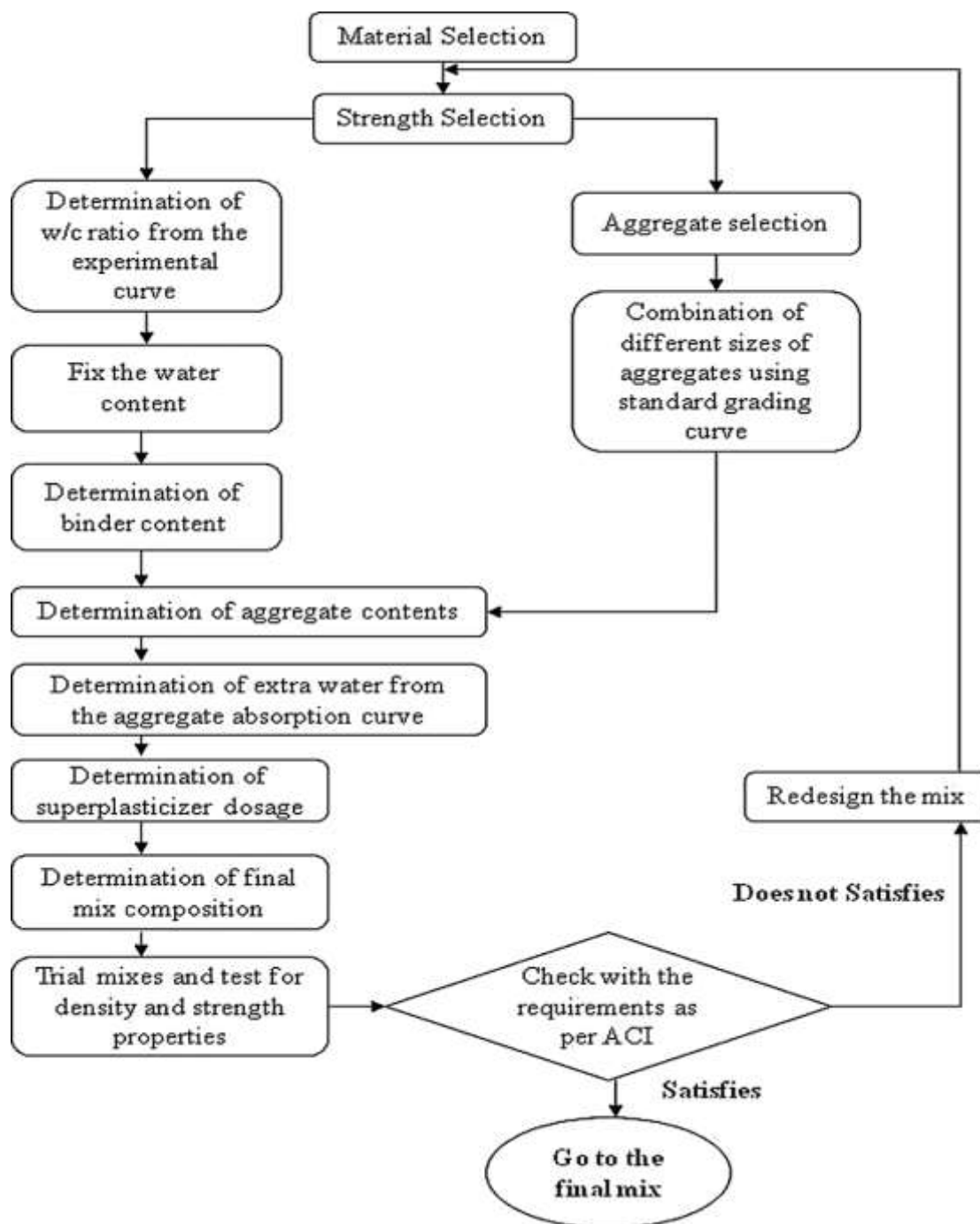


Figure 2 Flow chart of the proposed mix design methodology [24].

Kaszynska and Zielinski [25] reported the effect of lightweight aggregate on minimizing autogenous shrinkage in self-consolidating concrete. For this, the authors used different proportions of Portland Cement CEM I 42.5 R, fly ash, silica fume, Sika viscocrete 3 superplasticizer and lightweight aggregate pollytag size of 0-4 mm and 4-8 mm, natural sand size of 0-2 mm (fine aggregate) and natural granite coarse aggregate size of 2-8 mm. The mixture proportions of the studied concretes and mortars are listed in Table 7 and Table 8, respectively. Their study revealed that unrestrained linear shrinkage of mortars measured with Auto-shrink method was largest for mortar with lowest w/c ratio. Replacing natural coarse aggregate with lightweight aggregate Pollytag reduces the shrinkage not only in the first 24 hour but also after demolding of specimen.

Table 7 Composition of self-consolidating concretes [25].

Mix	Cement [kg/m ³]	Additives [kg/m ³]		Water [kg/m ³]	SP [kg/m ³]	Aggregate [kg/m ³]			
		Fly ash	Silica fume			Natural		Pollytag	
M-1	450	72	38	155	11	0-2	2-8	0-2	4-8
						624	1072	-	-
M-2	450	72	38	155	7.65	624	-	-	540
M-3	450	72	38	155	7.65	-	-	310	540

Table 8 Composition of self-consolidating mortars [25].

Mortars	Cement [kg/m ³]	Additives [kg/m ³]		Water [kg/m ³]	SP [kg/m ³]	Fine Aggregate [kg/m ³]	w/c
		Fly ash	Silica fume				
Z-1	450	72	38	113	20	735	0.25
Z-2	450	72	38	155	9	624	0.34
Z-3	450	72	38	180	4.5	557	0.40

hung et al. [26] studied the effects of expanded polystyrene (EPS) sizes and arrangements on the properties of lightweight concrete. In their study, they modeled a set of virtual lightweight concrete samples with different expanded polystyrene sizes and distribution (Figure 3). The materials used were CEM I 42.5 R and natural sand (0-2mm). The cement: sand ratio was 1: 2 and the water/ cement ratio was 0.45. The specimen preparations with the regular arranged expanded polystyrene aggregates are shown in Figure 4. Some of the results of their study are illustrated in Figure 5, Figure 6 and Figure 7.

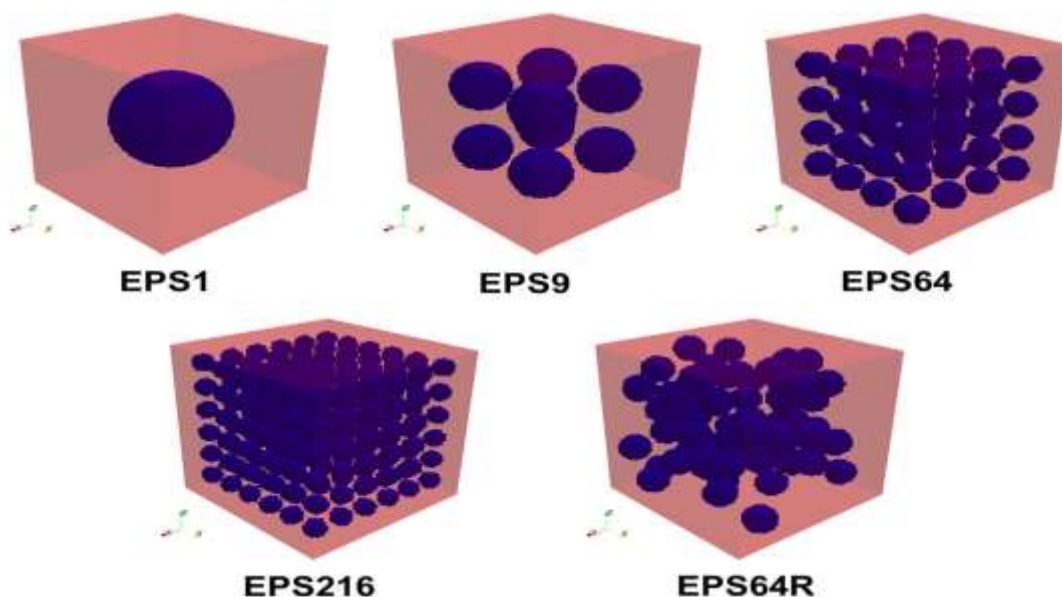


Figure 3 Virtual lightweight concrete samples with different EPS aggregate sizes with regular arrangement

(Note In each sample, the blue regions represent EPS aggregates, and the red region is solid (mortar).

The samples EPS1, 9, 64, 216 have regular arrangements, while EPS64R is the sample with a random distribution of the 64 EPS aggregates. The volume ratio of the EPS aggregates for all samples is the same as 12.5%) [26].

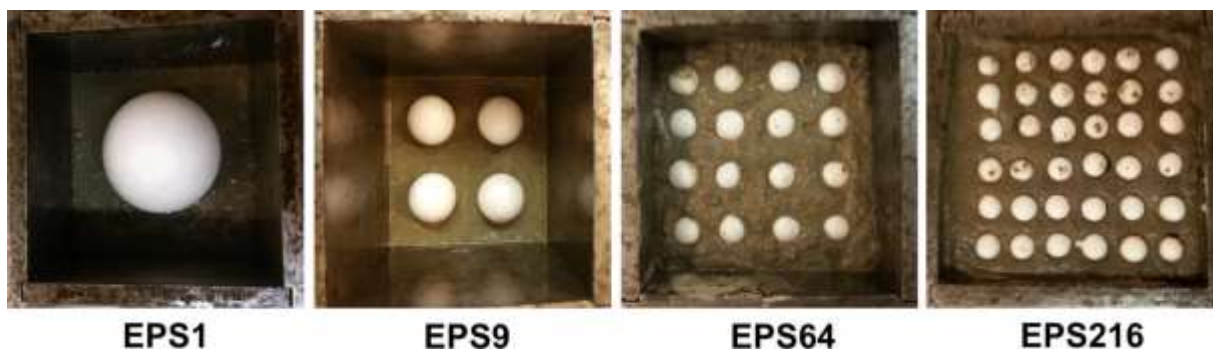


Figure 4 EPS lightweight concrete specimens with different sizes and distributions

(Note the volume ratios of the EPS aggregate specimens are set to be about $12.5 \pm 0.2\%$) [26].

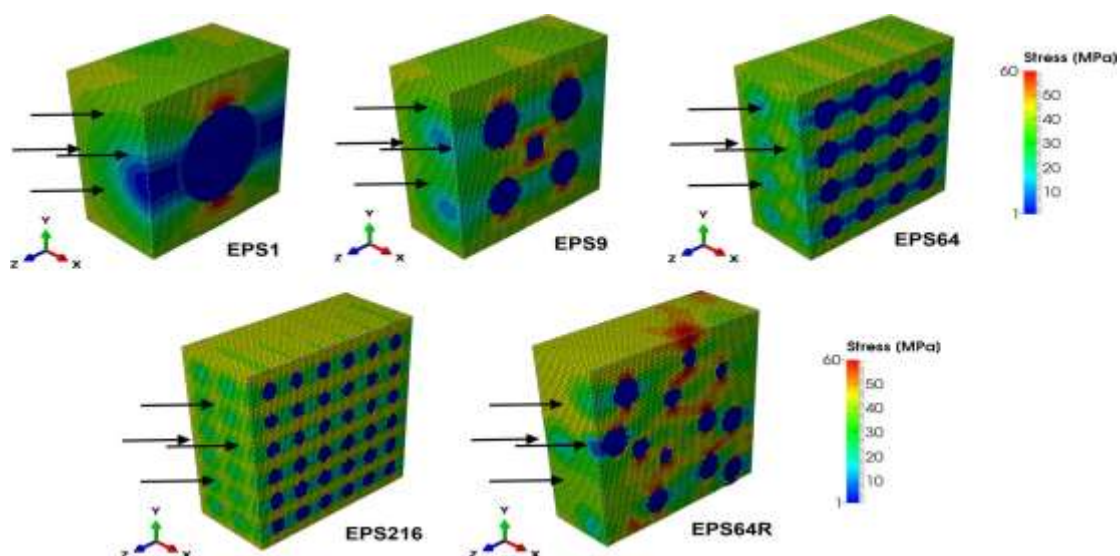


Figure 5 Stress contour of the designed samples with different EPS aggregate sizes

(Note the values on the color bar represent the von Mises stress [MPa]) [26].

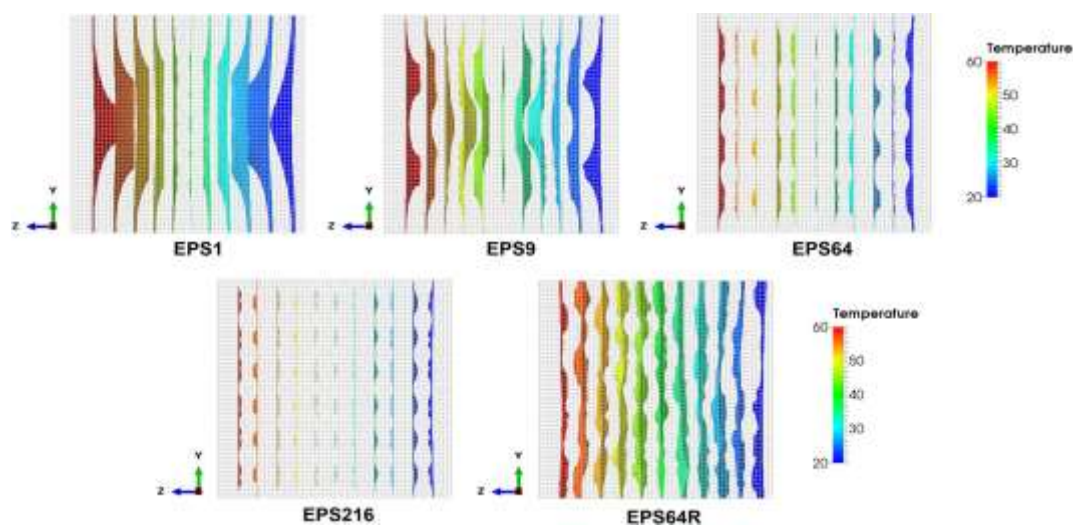


Figure 6 Temperature isosurfaces of the designed samples with different EPS aggregate sizes (Note the values on the color bar represent temperature [°C]) [26].

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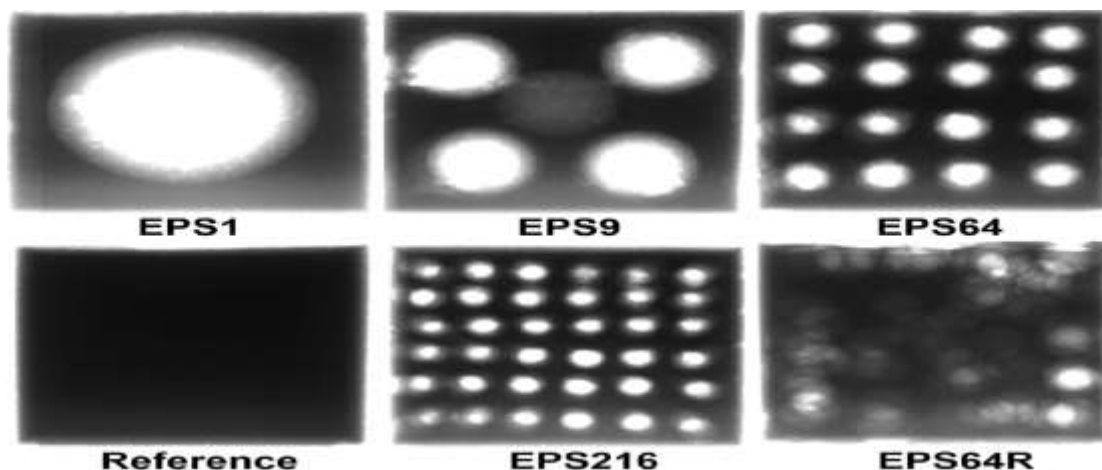


Figure 7 Radiography images of EPS aggregate concrete specimens [26].

Cui et al. [27] presented the effect of slag on durability of lightweight concrete and report water permeability and carbonation depth of this kind of concrete. The materials used in the production of lightweight concrete were: Ordinary Portland cement, expanded clay as lightweight aggregate, ground granulated blast-furnace (GGBS), medium river sand as fine aggregate, Grace DAVA 109 as water-reducing admixture. Table 9 reports the mixture proportions of the lightweight concretes tested. 100x100x100 of 18 cube samples were casted. Their study revealed that the permeability coefficient of the lightweight concrete decreased remarkably as the GGBS dosage increased, and the carbonation depth of the concrete increases as dosage increases.

Table 9 Mixture proportions of the lightweight concretes [27].

Mix No.	W/C	GGBS (mass %)	Cement (kg/m ³)	GGBS (kg/m ³)	Water (kg/m ³)	Lightweight Aggregate (kg/m ³)	Sand (kg/m ³)
3-0	0.50	0	350	0	175	502	804
3-1	0.50	25	337.5	87.5	175	502	796
3-2	0.50	40	270	140	175	502	789

Shafigh et al.[28] reported an experimental study on the effect of cement replacement with type F fly ash at 0%, 10%, 30% and 50% on some engineering properties of an oil palm shell (OPS) high strength lightweight concrete and report workability, density, compressive strength, splitting tensile strength, flexural strength, water absorption and drying shrinkage properties. Based on test results, the authors outlined that the substitution of cement by fly ash (by mass) in OPS concrete reduced its density. OPS concrete containing a higher amount of fly ash has greater water absorption. When fly ash is used in OPS concrete, its sensitivity to lack of curing increases.

Shafigh et al. [29] investigated the stress–strain behavior and E value of grade 30, 40 and 50 crushed oil palm shell (OPS) concrete and reported that the E value of crushed OPS expanded clay lightweight concrete (LWC) was approximately 53% of the control granite normal weight concrete (NWC).

Page et al. [30] studied the properties of hemp concrete with viscosity-modifying admixture. Some of their results are presented in Figures 8, 9 and 10.

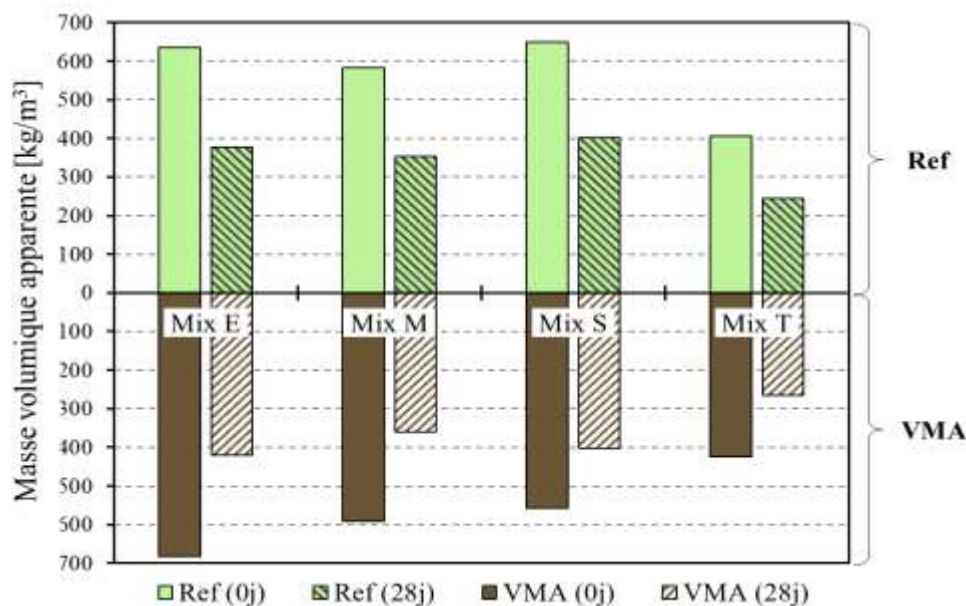


Figure 8 Apparent density of hemp concretes [30].

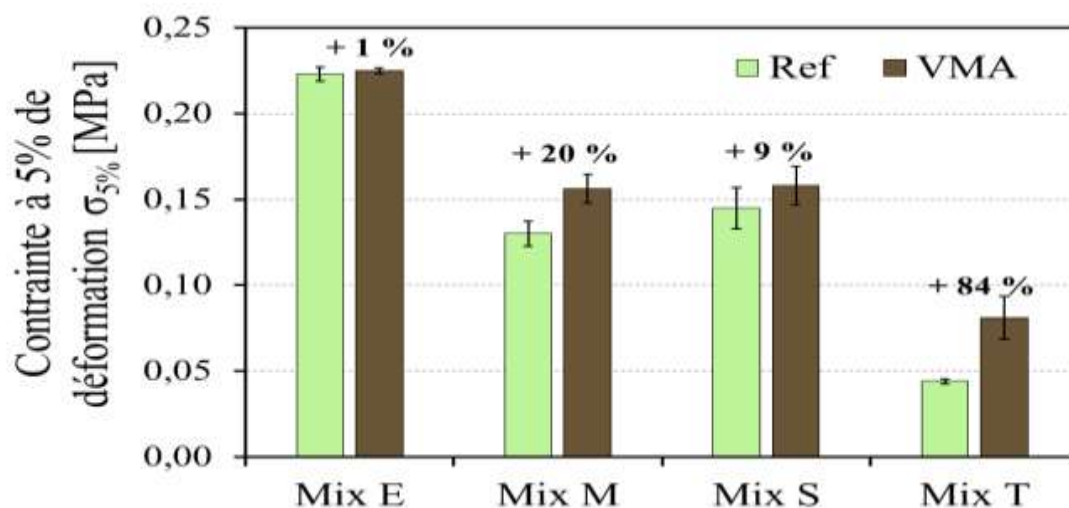


Figure 9 Compressive strength of hemp concretes [30].

The results published by Patel et al. [31] indicated that the compressive strength decreases with the increase in proportion of Styrofoam in the mix and that the mass of the specimen decreases with the increase in proportion of Styrofoam in the mix.

In a research by Gradinaru et al. [32] which examined the possibility of using the sunflower stalks as an ecological and sustainable alternative for mineral aggregates of the conventional concrete composition, it was found that the replacement of mineral aggregates in a proportion of 50% with the sunflower aggregates led in a decreasing of mechanical properties of the concrete. The treatment of sunflower aggregates with more concentrated solution of sodium silicate resulted in a significant improvement of the compressive and tensile strengths of concrete comparing to the concrete manufactured with untreated sunflower aggregates

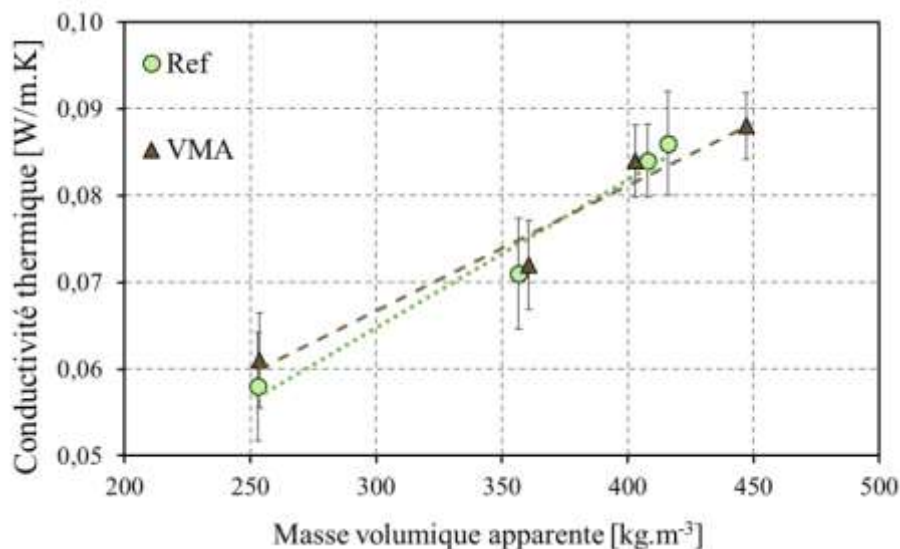


Figure 10 Thermal conductivity of hemp concretes as a function of apparent density [30].

3. 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 charcoal aggregate concretes (LWAC).

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

3.1 Materials

3.1.1 Cement

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. 11 and 12, respectively. Tab. 10 reports physical and mechanical characteristics.

Table 10 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 (cm ² /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

Table 11 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

Table 12 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%

3.1.2 Sand

3.1.2.1 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. 11) of the particle size analysis by sieving method conform to NF P 18-101 [33], show that D₁₀ = 0.15 mm, D₃₀ = 0.48mm and D₆₀ = 1.2 mm.

From the grading curve, the values of D₁₀, D₃₀ and D₆₀ enable us to calculate the coefficient of uniformity of HAZEN (C_u) and the coefficient of curvature (C_c), we have:

D₁₀= 0.15mm; D₃₀= 0.48mm and D₆₀= 1.2mm.

¶And:

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

Also:

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

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

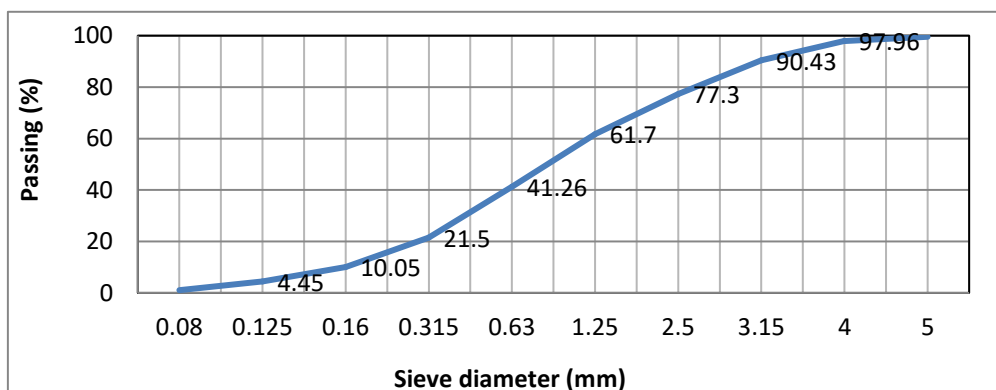


Figure 11 Particle size distribution curve of sand 0/5 used

Characterization of Lightweight Concrete Impregnated with Cement and Cameroonian Charcoal as Coarse Lightweight Aggregate

3.1.2.2 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) (Fig.12, Fig.13 and Fig.14) 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.



Figure 12 Rinsing the walls of the test piece



Figure 13 Clogging of the test piece



Figure 14 Measurement using the ruler

Table 13 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. 13 above, we observe that the Sanaga sand is justified for our study. NF XP P 18-540 [34] 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) [35], the good sand must have a fineness modulus around 2.5.

3.1.2.3 Density

The absolute density of the sand was measured using a pycnometer. This test was conducted as follow: After drying a certain quantity of the sand in the oven for 24hours (Fig. 15) we weigh it (M) (Fig. 16), we filled the pycnometer with water and weigh it (M1) and then we poured the sand into this pycnometer and weigh it (M2) (Fig. 17).

The absolute density of the sand was calculated using the formula:

$$\rho_r = \rho_0 \cdot M / (M1 + M - M2)$$

Where: M1 (g) is the mass of the pycnometer + water

M (g) is the mass of the sand sample

M2 (g) is the mass of the pycnometer + water + sand

ρ_0 is the density of the water

Table 14 shows the average of individual results. The results (Table 14) obtained from three sand samples show that, from one measure to another, the density of the sand is not very different.

Characterization of Lightweight Concrete Impregnated with Cement and Cameroonain Charcoal
as Coarse Lightweight Aggregate



Figure 15 Drying of the sand



Figure 16 Sand Weighing



Figure 17 Weighing the pycnometer + water + sand

Table 14 Absolute density of sand

	Symbol	N ^o of Sample		
		N ^o 1	N ^o 2	N ^o 3
Mass of the pycnometer + water (g)	M1	637.83	620.83	640.21
Mass of the sand sample (g)	M	100	100	100
Mass of pycnometer + water + sand (g)	M2	699.33	681.83	702.21
Absolute density (t/m ³)	$\frac{\rho_0 \cdot M}{(M1 + M - M2)}$	2.597	2.564	2.631
Average of individual results (t/m ³)		2.597		

ρ_0 is the density of the water ($\rho_0 = 1 \text{ t / m}^3$)

3.1.3 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 [36]. 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 [36].

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) [37] 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).

3.1.4 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. 18) in North West Region, Bamenda, Cameroon.



Figure 18 eucalyptus plant in Bamenda.

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

Characterization of Lightweight Concrete Impregnated with Cement and Cameroonain Charcoal as Coarse Lightweight Aggregate

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 22 shows the particle size distribution curve.

- Water absorption rate

The water absorption rate test was performed on three (03) samples of charcoal. The results (Table 15) showed that the water absorption rate of the charcoal used is 73.04% (average of individual results). The water absorption test was conducted for quantifying the quantity of water which infiltrates in the pores of the pieces of charcoal, this water not being able to take part in the hydration reaction of the cement. After drying the pieces of charcoal in an oven (Fig.19) until constant mass we weigh it (M_s) (Fig. 20), we immerge the sample in water for 24 hours (Fig. 21) and weigh it (M_a) and measure the mass of the sample thus sponged. The water absorption rate of charcoal was calculated using the following equation:

$$\text{Water absorption rate (\%)} = (M_a - M_s) / M_s$$

Where: M_s is the dry mass of the sample (g)

M_a is the mass of the sample after immersion (g)

Table 15 Water absorption rate of charcoal

	Symbol	N ^o of Sample		
		N ^o 1	N ^o 2	N ^o 3
Dry mass of the sample (g)	M_s	404.50	419.11	398.21
Mass of the sample after immersion (g)	M_a	716.16	706.19	691.14
Water absorption rate (%)	$\frac{M_a - M_s}{M_s} * 100$	77.05	68.49	73.56
Average of individual results (%)		73.04		



Figure 19 Drying of charcoal in an oven



Figure 20 Weighing charcoal after drying



Figure 21 Immersion of charcoal

- Absolute density

The absolute density was measured using a pycnometer. The results (Table 16) obtained from three (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). The following steps were used for conducting this test:

- Take a graduated cylinder and fill it to a certain water level (Fig. 23), read the volume V_1 then, weigh this test tube and raise the mass M_1 .

Characterization of Lightweight Concrete Impregnated with Cement and Cameroonain Charcoal as Coarse Lightweight Aggregate

- Take a certain amount of charcoal (this will depend on the size of the specimen). No need to weigh the mass of sample taken.
- Pour this charcoal into the test tube, read the new volume V2 then weigh this test tube and read the mass M2 (Fig. 24). The absolute density was calculated by applying this equation:

Absolute density (t/m³) =	$\frac{M2 - M1}{(V2 - V1)}$
---	-----------------------------

Where: M1 is the mass of the specimen with water (g)

V1 is the volume of water contained in the test tube (ml)

M2 is the mass of the specimen + water + charcoal (g)

V2 is the volume of water + charcoal (ml)

Table 16 Absolute density of charcoal

	Symbol	N ^o of Sample		
		N ^o 1	N ^o 2	N ^o 3
Mass of the specimen with water (g)	M1	326.03	311.16	321.13
Volume of water contained in the test tube (ml)	V1	200	200	200
Mass of the specimen + water + charcoal (g)	M2	363.8	349.11	363.16
Volume of water + charcoal (ml)	V2	273.1	264.2	269.5
Absolute density (t/m ³)	$\frac{M2 - M1}{(V2 - V1)}$	0.516	0.591	0.604
Average of individual results (t/m ³)		0.57		



Figure 23 Weighing the specimen containing water



Figure 24 Weighing the specimen containing water and charcoal

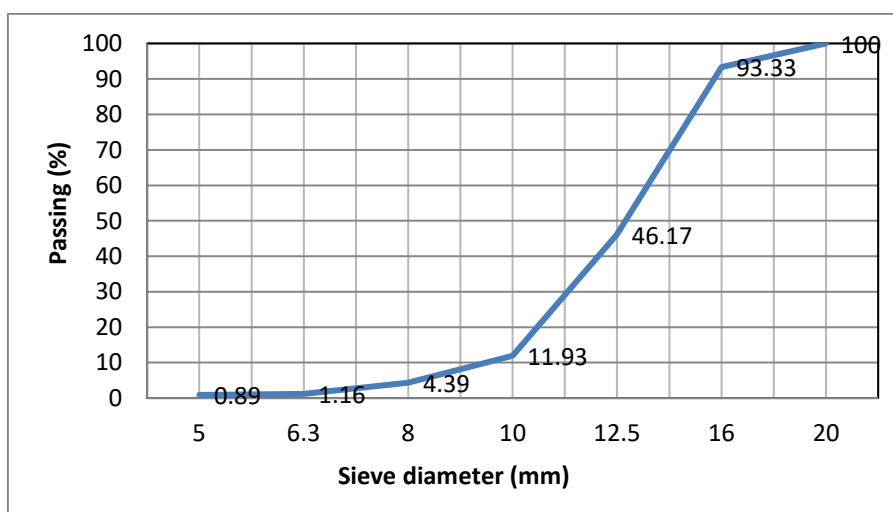


Figure 25 Particle size distribution curve of charcoal 5/20 used.

4. 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 objectives of this research are to develop a lightweight concrete made with Cameroonian charcoal as coarse lightweight aggregate and to evaluate its absorption, density and mechanical performance. 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 [12]. Two methods were chosen for the composition of the materials 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.

4.1 Dreux-Gorisse Formulation Method

4.1.1 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.

Table 17 Mixture proportions for concrete samples (1m³).

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

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. 17.

4.2 Progressive formulation method

This method is based on a choice of a cementitious matrix that assigns a desired lightweight concrete, it is called MO, 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 five 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. 18 below.

Table 18 Compositions of the different mixtures.

Constituents (Kg/m ³)	M0	M25	M50	M75	M100
Charcoal	0	337.5	675	1012.5	1350
Sand	1350	1012.5	675	337.5	0
Cement	450	450	450	450	450
Water	225	225	225	225	225
g (%)	0%	25%	50%	75%	100%
W/C	0.5	0.5	0.5	0.5	0.5

4.3 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. 17 and Tab. 18, respectively. The mixing sequence of the constituent materials was as follows: Charcoal was mixed with cement for two minutes to

homogenize the mixture and then extended for another two minutes after the sand has been incorporated (Figure 25). The mixing water is then added, and the mixing is continued for two minutes. The mixing was done correctly to obtain a homogeneous mixture with uniform properties [38].



Figure 25 Dry mixing of different constituents of concrete

A flow chart of the methodology adopted to perform the experimental programme is given in Figure 26.

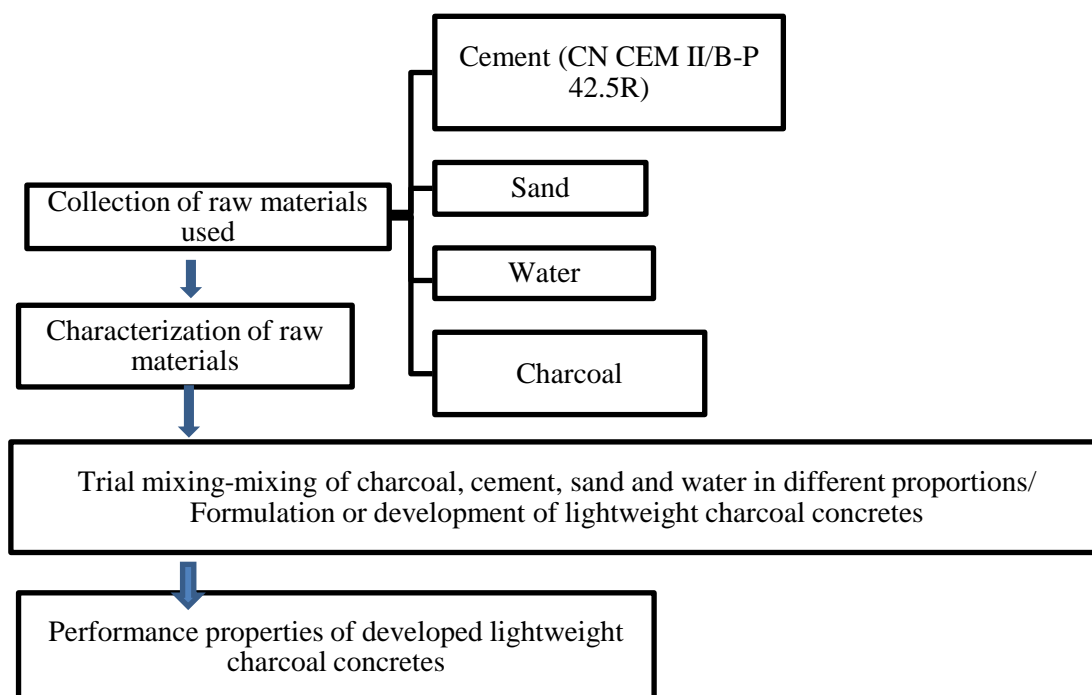


Figure 26 Research framework

5. TESTING METHODS

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

5.1 Apparent density test

The Apparent density test was conducted on specimens of size $4 \times 4 \times 16 \text{ cm}^3$. After preparing the samples, they were removed from the mold the day and stored in drinking water to prevent any water exchange with the outside, the temperature was kept constant at $20^\circ \text{C} \pm 1^\circ \text{C}$. Then, the weight (M) (Figure 27) and the dimensions of the sample were recorded and the volume (V) of the sample was calculated. The apparent density of the samples was calculated as follows:

$$D=M/V \quad (1)$$

Where: M is the mass and V the volume of the tested sample.



Figure 27 Measurement of the mass of the concrete

5.2 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 (Figure 28) were oven dried for 48 hours, they then be weighed (W_1), then immersed in water for 24 hours (Figure 29) and weighed again (W_2). The percentage of water absorption (A) was computed for each sample using Equation 1.

$$A (\%) = \frac{W_2 - W_1}{W_2} \times 100 \quad (2)$$

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



Figure 28 demolding of specimen



Figure 29 Immersion of concrete samples in water

5.3 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. 30) 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.

$$\sigma = F/S \quad (3)$$

Where: σ = compressive strength, F = maximum load applied before failure, S = cross sectional area of the specimen.



Figure 30 Compressive strength testing machine

5.4 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 [20, 36]. Interest in tensile properties has grown substantially in recent years partially due to introduction of fracture mechanics into the field of concrete structures [20, 36].

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

$$F_{tj} = 0.6 + 0.06f_{cj} \quad (4)$$

If f_{cj} less than 40 MPa. Where: f_{cj} = compressive strength at j day.

5.5 Three-Point Bending Test

The three-point bending tests were conducted to determine the flexural strength of concrete specimens at 7 and 28 days. The tests were conducted on 40×40×160 mm³ samples where the support span was 100 mm. The load was applied at the middle of the specimens (Figure 31) with a span length of 100mm. The breaking stress (σ) was calculated using the following equation:

$$\sigma = 3/2 (FL / b^3) \tag{5}$$

Where, F is the breaking force, L is the span (100mm), b being the edge of square section (b = 40 mm).

Thus, $\sigma = 2.34375 \times F$

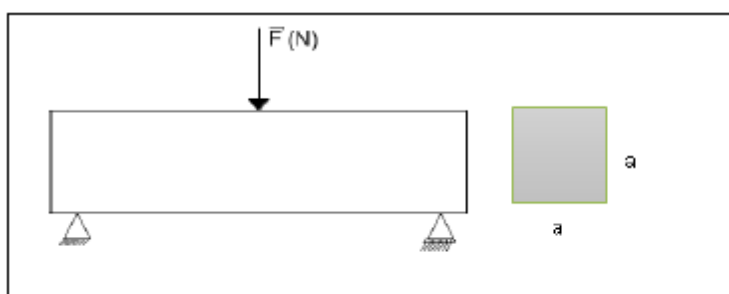


Figure 31 Geometry of the cross-section of the specimen for three-point bending test

6. RESULTS AND DISCUSSION

6.1 Workability of the Concrete Lightweight and its Apparent Density

Figure 32 presents a comparison between the workability of the concrete and its apparent density using the Dreux-Gorisse formulation method. It can be seen that, when the workability of the concrete increases, its apparent density decreases. So the more the concrete is workable, the less dense it is. The average apparent density is approximately 1422.445 Kg/m³. This is in line with the definitions of lightweight concrete given by the American Concrete Institute, the RILEM, the Eurocode 2, the German standard, DIN 1042 (1972). The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) define lightweight concretes as concretes with a dry density of less than 1800 Kg/m³. The American Concrete Institute (ACI) limits the bulk density of lightweight concrete to 1800 Kg/m³ after air drying for 28 days. The German standard, DIN 1042 (1972) limits the apparent density of a lightweight concrete to 2000 kg/m³. The Eurocode 2 limits the bulk density of lightweight concrete to 2200 Kg/m³ [11].

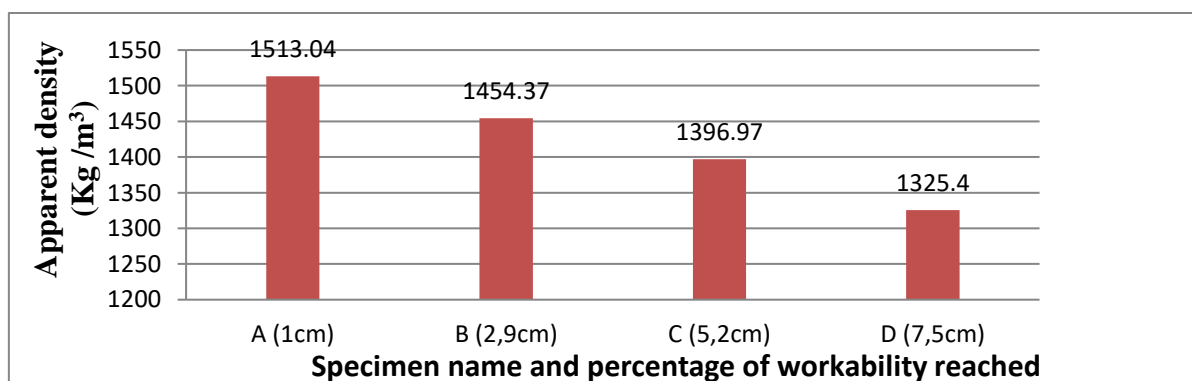


Figure 32 Variation of the apparent density of the concrete according to the workability

6.2 Effect or Influence of Charcoal on the Apparent Density of Concrete Specimens

The effect or influence of charcoal on the apparent density of concrete specimens using the progressive formulation method is shown in Fig 33. Specimen with charcoal exhibited lower apparent density than the control specimen. The apparent density of the control specimen is 1655 kg/m^3 . The apparent density of concretes decrease as the amount of charcoal increases in the mix. Charcoal is less dense than sand, so it is obvious that the substitution of sand by charcoal would lower the apparent density of concrete specimens. When the sands were substituted with charcoal aggregate contents at 25%, 50%, 75% and 100%, the apparent density values of concrete specimens were increased by 13.71%, 33%, 47.18% and 65.72%, respectively when compared with the control mix.

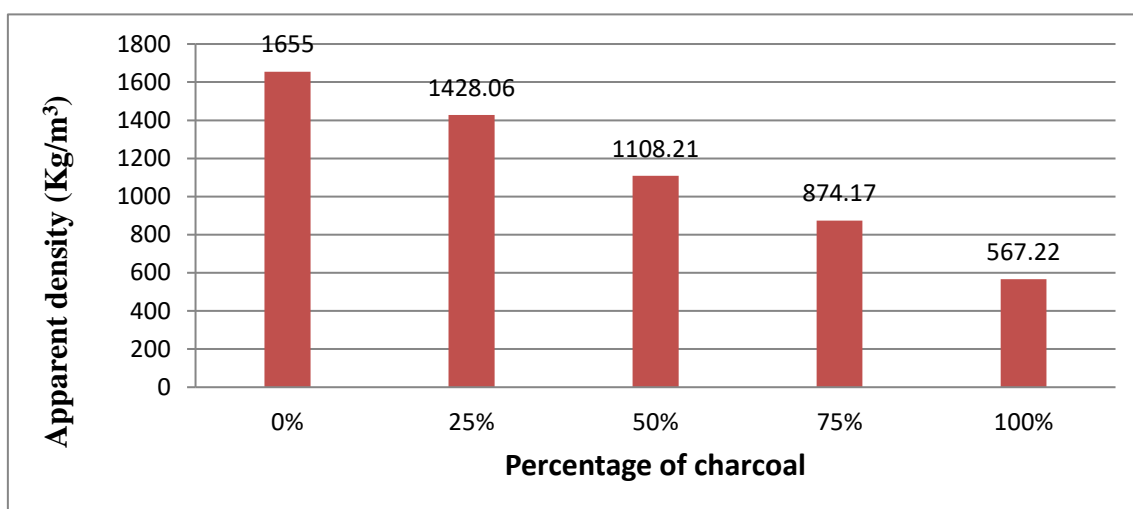


Figure 33 Apparent density of concrete as a function of charcoal content

6.3 Water Absorption of the Lightweight Concrete and its Density

Figure 34 shows 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.

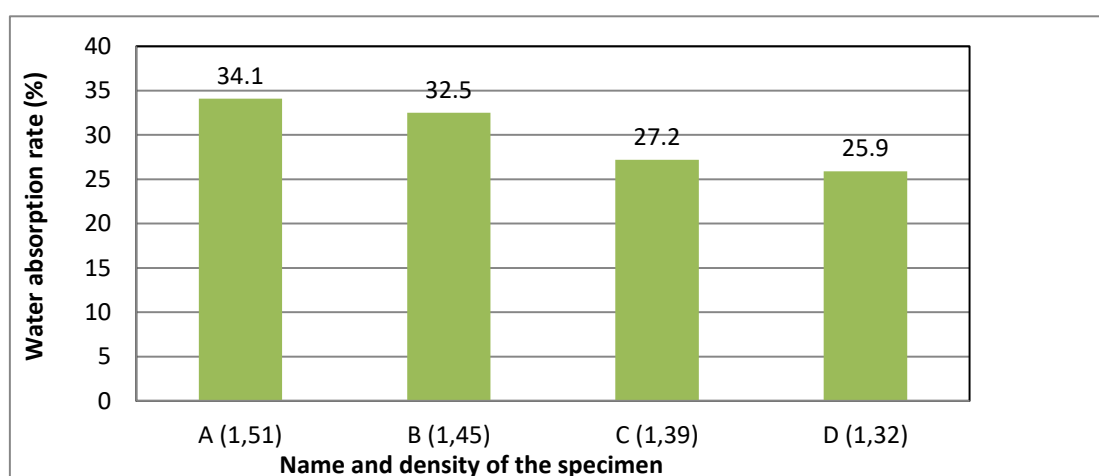


Figure 34 Variation of the rate of water absorption of the concrete as a function of its density

6.4 Effect or influence of charcoal on water absorption of concrete specimens

The results of the water absorption using the progressive formulation method are shown in Fig. 35. 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% charcoal replacement (control) had a lower water absorption compared to samples of 25%, 50%, 75%, and 100% charcoal replacement. When the sands were substituted with charcoal aggregate contents at 25%, 50%, 75% and 100%, the water absorption values of concrete specimens were increased by 74.60%, 87.90%, 90% and 91.65%, respectively when compared with the control mix.

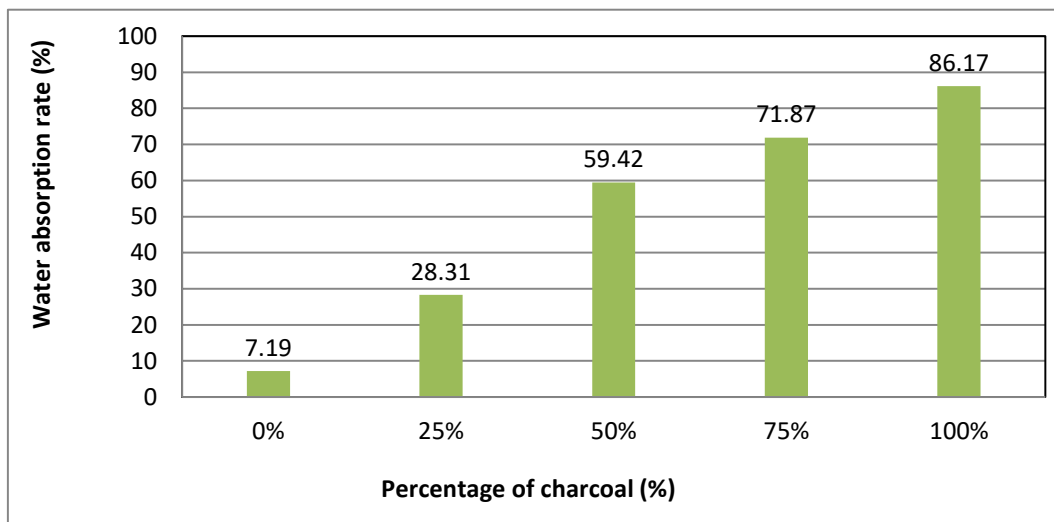


Figure 35 Water absorption rate of concrete as a function of charcoal content.

6.5. Compressive Strength with Respect to The Density and Curing Time

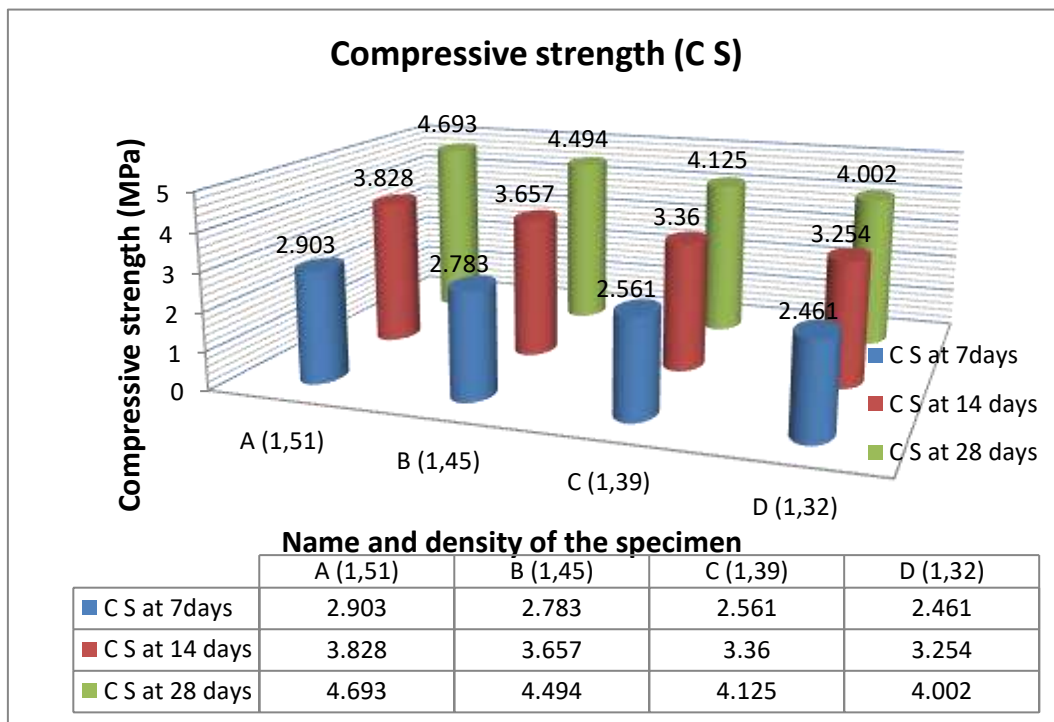


Figure 36 Compressive strength of concrete as a function of time and density.

The results of the compressive strength tests are shown in Fig. 36. The diagram shows the compressive strength with respect to the density and curing time using the Dreux-Gorisse formulation method. The American Concrete Institute (ACI) limits the bulk density of lightweight concrete to 1800 Kg /m³ after air drying for 28 days. It is observed from Figure 36, that all the mixtures are within the range for structural lightweight concrete. The density ranging from 1.32 t/m³ to 1.51 t/m³ or from 1320 Kg/m³ to 1510 Kg/m³. The compressive strength decreased with the reduction of the density of lightweight concrete. The compressive strength also increased as the curing time increased.

6.6. Effect or Influence of Charcoal on The Compressive Strength of Concrete Specimens

The variations of compressive strength of the control specimens and other specimens containing charcoal using the progressive formulation method are shown in Fig. 37. Samples of 0% charcoal replacement (control) had a greater compressive strength at each age compared to samples of 25%, 50%, 75%, and 100% charcoal replacement. 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) [39] 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) [40], NF P 14-304 (1983) [41], NF EN 771-3 (2011) [42] and NF EN 771-3 / CN (2012) [43], 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 and Cook [44] 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 low mechanical strength of lightweight charcoal concrete is also due to the high water absorption of charcoal aggregates (73.04%) and weak or poor bond between charcoal aggregate and binder.

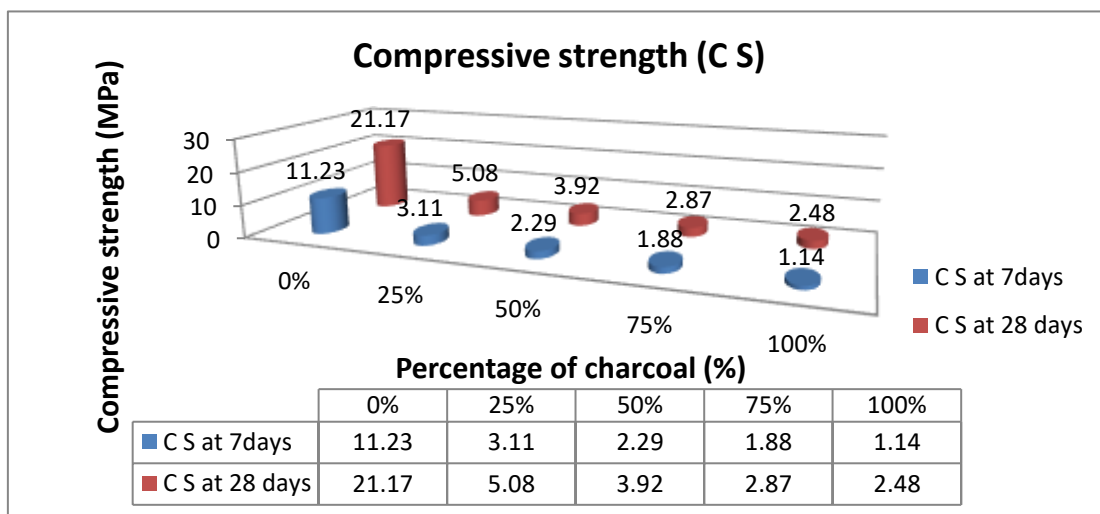


Figure 37 Compressive strength of concrete as a function of time and charcoal content.

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. When the sands were substituted with charcoal aggregate contents at 25%, 50%, 75% and 100%, the compressive strength (CS) values of concrete specimens were reduced by 72.30%, 79.60%, 83.25% and 89.84%, respectively at curing age of 7 days and were reduced by 76%, 81.50%, 86.44% and 88.28%, respectively at curing age of 28 days when compared with the control mix.

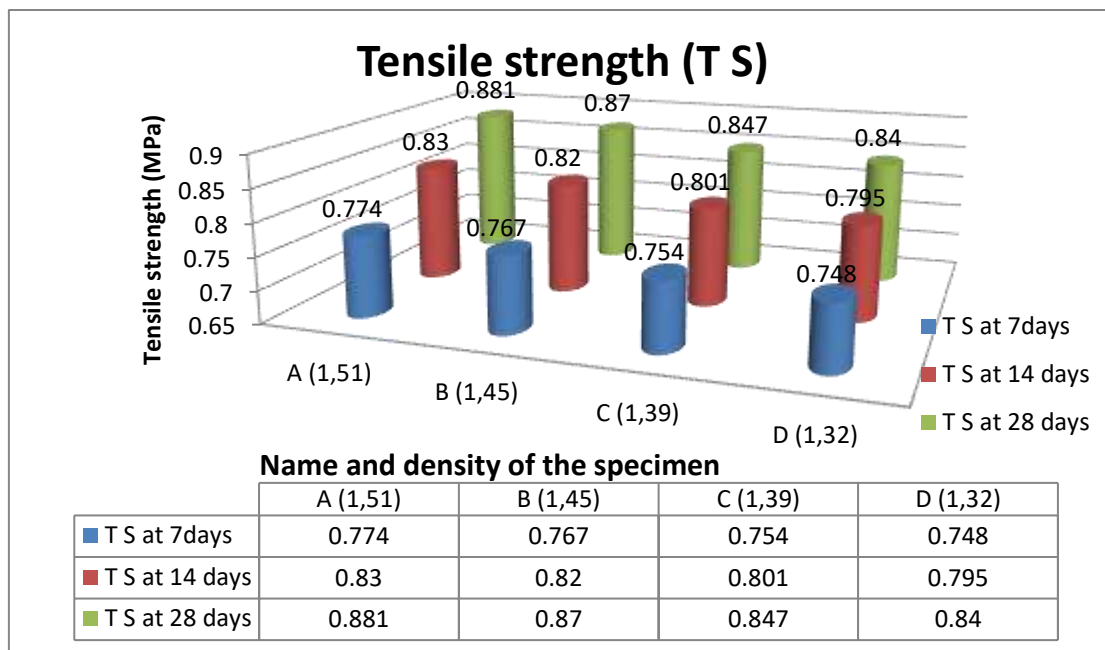


Figure 38 Tensile strength of concrete as a function of time and density.

6.7 Tensile Strength with respect to the Density and Curing Time

The variations of tensile strength with respect to the density and curing time using the Dreux-Gorisse formulation method are shown in Fig. 38. The tensile strength decreased with the reduction of the density of lightweight concrete. The tensile strength also increased as the curing time increased.

6.8 Effect or Influence of Charcoal on the Tensile Strength of Concrete Specimens

The variations of tensile strength of the control specimens and other specimens containing charcoal using the progressive formulation method are shown in Fig.39. Samples of 0% charcoal replacement (control) had a greater tensile strength at each age compared to samples of 25%, 50%, 75%, and 100% charcoal replacement. 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. When the sands were substituted with charcoal aggregate contents at 25%, 50%, 75% and 100%, the tensile strength (TS) values of concrete specimens were reduced by 37.80%, 42.51%, 44%, respectively at curing age of 7 days and were reduced by 48%; 51.87%, 58.82% and 60%, respectively at curing age of 28 days when compared with the control mix.

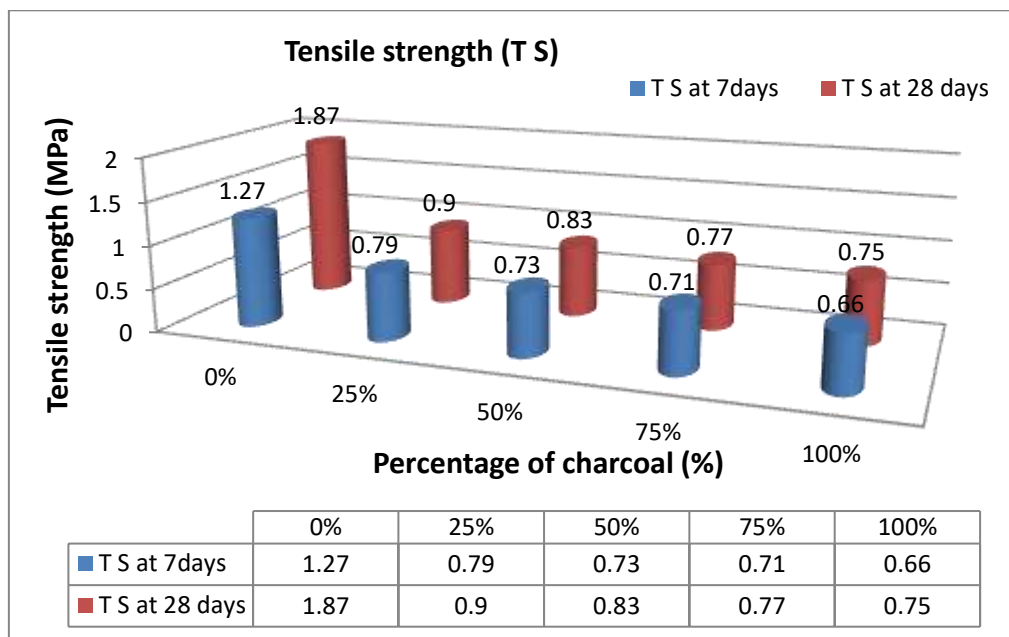


Figure 39 Tensile strength of concrete as a function of time and charcoal content.

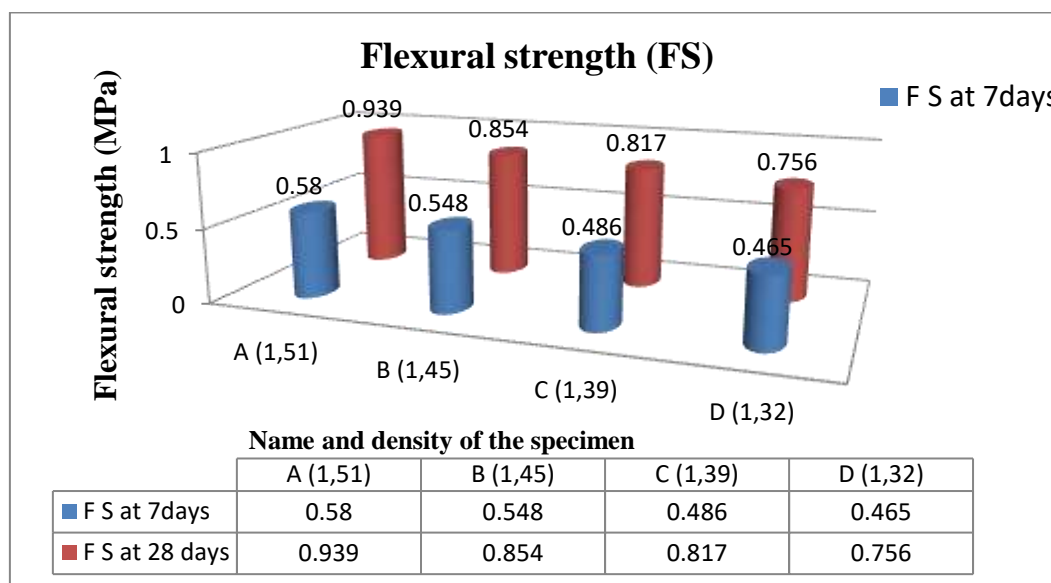


Figure 40 Flexural strength of concrete as a function of time and apparent density

6.9 Flexural Strength of Concrete Specimens and its Apparent Density

The results obtained for the flexural strength (F S) tests at curing ages of 7 and 28 days for eight specimens of concrete using the Dreux-Gorisse formulation method are illustrated in figure 40. It can be seen that as the apparent density of concrete decreases, the flexural strength also decreases. But this resistance increases with curing age.

6.10 Effect or Influence of Charcoal on the Flexural Strength of Concrete Specimens

Figure 41 shows the influence of charcoal on the bending or flexural strength (FS) of concrete specimens at curing ages of 7 and 28 days using the progressive formulation method. It can be seen that as the amount of charcoal increases in the concrete, its resistance to bending decreases.

The control specimens have a flexural strength of 3.51 MPa and 5.13 MPa at 7 and 28 days of maturity, respectively. The optimum flexural strength was obtained at 25% of charcoal replacement. The flexural strengths of concretes increase with the increase in curing age in all the specimens. When the sands were substituted with charcoal aggregate contents at 25%, 50%, 75% and 100%, the bending or flexural strength (FS) values of concrete specimens were reduced by 59.25%, 78.34%, 86% and 88%, respectively at curing age of 7 days and were reduced by 56.53%, 67%, 88% and 91%, respectively at curing age of 28 days when compared with the control mix.

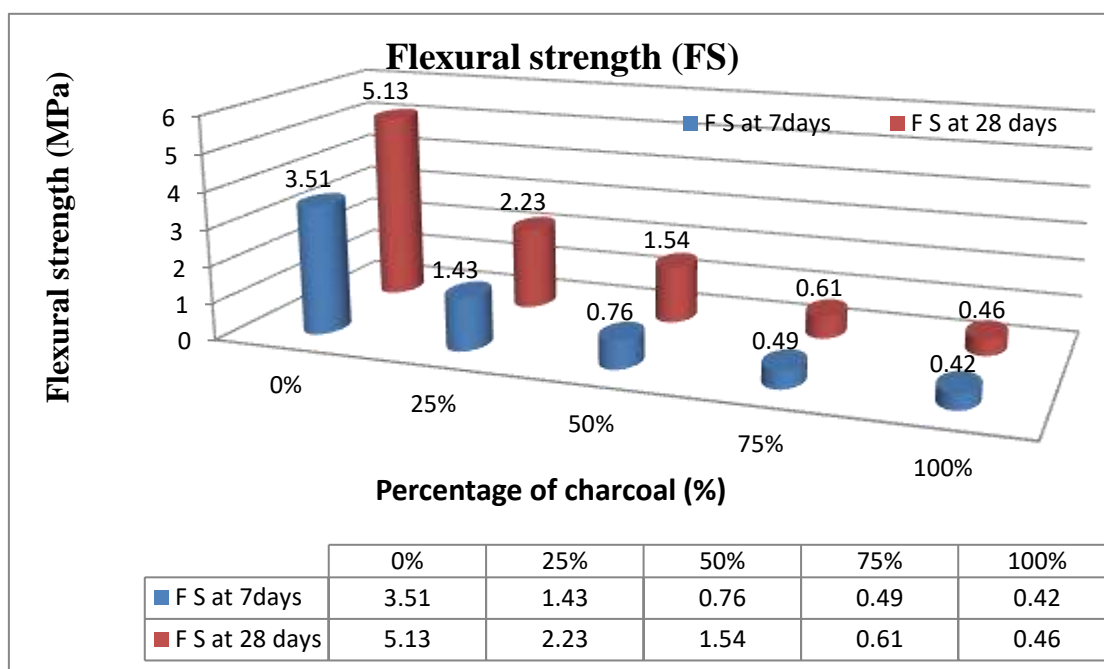


Figure 41 Resistance to bending of concrete as a function of time and charcoal content

7. CONCLUSIONS

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

Although lightweight concretes have been known around the world for over a quarter of a century, they are not employed yet in Cameroon. The possibility of substituting the conventional aggregates in the conventional 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/m³.
- The particle size distribution curve of the sand used showed that we have continuously graded sand with a fineness modulus of 2.68.
- The absolute density of sand used is 2.6 t/m³.
- 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 compressive, tensile and flexural strengths of concretes increase with the increase in curing time in all the mixes and the evolution from one formulation to another is rather similar.
- The apparent density of the concrete decreases with the increase in charcoal content
- The flexural strength and tensile strengths evolve in a manner similar to that of compressive strength.

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