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ORIGINAL RESEARCH PAPER

Engineering and Mineralogical Properties of Portland Cement Used for Building and Road Construction in Cameroon

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Abstract

In this study, the engineering characteristics of Portland cement samples (CM1, CM2, CM3 and CM4) from four manufacturers in Cameroon were evaluated to know their physical and mineralogical properties to be used in different environments. For this purpose, many analyses such as physical properties (setting time, consistency, compressive strength, flexural strength, water absorption and apparent density) and mineralogical properties (XRF and XRD) have been analysed. The results from XRF, XRD and with Bogu's calculation revealed the predominance of alite (C_3S) for CM1, alite–belite for CM2 and belite for CM3 and CM4. The initial setting time observed was 193 min for CM2 higher than CM1, CM4 and CM3 with respective initial setting time as 188 min, 178 min and 173 min. The normal consistency obtained was 0.34, 0.33, 0.31 and 0.30 *W/C* ratio, respectively, for CM2, CM1, CM4 and CM3. The compressive and flexural strength after 28 days for mortars were, respectively, 43.8 MPa and 4.8 MPa for CM4, 41.8 MPa and 4.8 MPa for CM3, 43.9 and 4.2 MPa for CM1, 41.4 MPa and 4.1 MPa for CM2. The water absorption and apparent density of mortars were, respectively, 2.35 wt% and 2.16 g/cm^3 for CM1, 1.74 wt% and 2.18 g/cm^3 for CM2, 1.8 wt% and 2.17 g/cm^3 for CM3, 1.55 wt% and 2.19 g/cm^3 for CM4. Results from the chemical composition show that, CM2 has a higher value of alumina which contributes to the reduction of humidity in the building and the high value of iron oxide might cause the corrosion of the armature in humid building environments. The alite cement CM1 and belite cement CM4 gives better mechanical strength in tropical region.

Keywords Portland cement · Mechanical properties · Cement constituents · Bogu's calculation · Cameroon

1 Introduction

Portland cement is one of the most used cement for building and road construction in the world given the increasing requirements for this cement [1, 2]. The emergence of Portland cement as a material of choice has greatly impacted positively on the construction industry. The selection of a particular brand of cement among various ones in the production of concrete, for highway pavement design is a great call for concern [3]. The great impact is due to the fact that Portland cement shows advantages such as great resistance to cracking and shrinkage with faster setting time, high early strength and micro expansion for construction and maintenance [2, 4, 5]. However, advancements have been made in cement technology which includes improvement in the speed of construction and the durability of the cement so as to reduce the serious problem that are subjected to environmental exposure [6]. Calcined lime and clay are major ingredients for Portland cement. Cement is used as a binder for the production of mortar, plaster and concrete for building and road construction. Natural activities like heavy rains and flooding conditions in various part of the roads causes severe effects on the majority of these unpaved roads. The majority of soil materials lack the desire shear strength

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and sturdiness so they need to be improved by stabilization process with Ordinary Portland Cement and make them suitable for building and road construction [7–10]. Clay provides silica, alumina and little amount of iron, while calcined lime provides calcium oxide in the Portland cement [5, 11]. Cement mix with water can bind material together such as sand and bricks; it can be defined as a hydraulic binder which when mixed with water forms a paste, which sets and hardens by the process of hydration reaction [12]. After hardening even under water, strength is retained. Cement production plays a vital role in economic development by creating job opportunities [10, 13]. Portland cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregate to produce concrete. The hardness of Portland cement is mostly due to the hydrated minerals components such as CSH and CASH from calcium silicate (C_2S, C_3S) and calcium aluminate (C_3A), respectively. The hydrated component gives rigidity to cement and adhere strongly to the non-hydrated grains [14, 15].

Recent studies show several types of Portland cement of class 42.5 R used for construction [14, 16–19]. Where most of the Portland cement found in Cameroon market are mixed to 60–80% of aggregates before used [14]. To have an optimum yield, the knowledge of the characteristic of cement is primordial to optimize mortar, plaster or concrete in better conditions. In Cameroon, some properties and environmental use of most cements are not well known. It is in this light that a series of studies were carried out to analyze the physico-mechanical properties and chemical composition of various cement sold in the Cameroonian market. The physico-mechanical and hydraulic properties of the different Portland cement can be improved (specific surface area of cement powder, compressive and flexural strength of mortar, setting time and water/cement ratio of cement paste etc.) to classify and orient their uses.

The main objective of this study was to know the engineering and mineralogical properties of four Cameroonian Portland cements to optimize their use according to the different climatic regions in Cameroon. The specific objectives were to know the engineering properties (consistency, setting time, water absorption, apparent density, compressive strength and flexural strength) and chemical with mineralogical composition, calculation factors and the optimization of cement properties according to different climatic zones in Cameroon.

2 Material and Experimental plan

2.1 Material

2.1.1 Cameroonian Portland Cement

Four different types of Portland cement, CM1, CM2, CM3 and CM4 found in the market following the Cameroonian norm NC 234:2009–06 were used. The cement samples were collected directly from the market. The cement CM1 (CD) and CM2 (CR) correspond to Portland limestone cement with the class CEM II/A-P 42.5R and contains 80–94% clinker, 6–20% natural pozzolan and 0–5% secondary constituent, the cement CM3 (CC) correspond to Portland pozzolan cement CEM II/42.5R contains 80–94% of clinker, 6–20% of natural pozzolan and 0–5% secondary constituent. In addition, the cement CM4 (CM) correspond to Portland pozzolan cement with the class CEM II/B-P 42.5R contains 80–94% of clinker, 6–20% of natural pozzolan and 0–5% secondary constituents.

2.1.2 Normal Sand

The sand used in this study was collected from Sanaga river Ebedda Centre Region (Cameroon). The sand was washed, weighed and then passed through a 2 mm sieve to eliminate the coarse particle. The sand was later washed again, dried and sieved in a 0.08 mm sieve to eliminate clays, fine sand and plant materials and prevent agglomeration of grains that might lead to false results. It was dried in the dryer for 24 h at 105 °C and separate in different fractions according to EN 933-1, EN 933-3 [20, 21]. Figure 1 presents the granulometric curve of the normalized sand. The curves show a

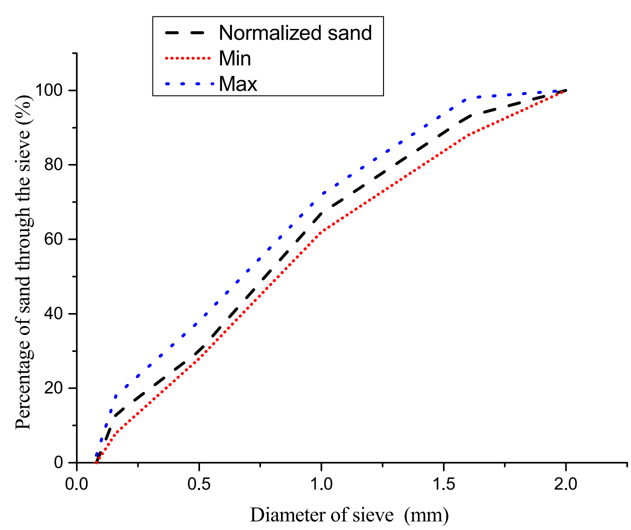

Fig. 1 Granulometric curve of normal sand

maximum and minimum size of sand with different percentages. The curve of normal sand (black color) obtained is between the upper one (blue color) and the lower one (red color). Normal sand elaborated from Sanaga sand respect the European norm EN.933-1, EN 933-3 [20, 21]. Good quality sand must have smooth and fine grains which covers the empty areas and thus reduces the volume of cement and liberate heat from the mortar.

2.1.3 Sample's Preparation

For cement mortar, water and cement were mixed immediately and the normalized sand added into the mixture after 30 s following the norm EN 1015-2:1999 [22]. The mixer was then stopped after 1 min and 30 s. The mortar was then put into the required prismatic mould with shape of 40 mm × 40 mm × 160 mm for flexural strength and compressive strength. The mortar was then demoulded after 24 h and cured for 28 days in water at 20 °C. The experimental protocol of cement mortar is presented in Fig. 2.

2.2 Laboratory Tests

2.2.1 Consistency of Cement Paste

The consistency of cement paste is defined as the percentage of water requirement of cement paste in which the viscosity of paste before setting for optimal properties obey at certain norms. The Consistency test has been assessed according to American Norm ASTMC0187-16 [23] to find out the amount of water in the cement paste using the vicat apparatus. With a mass of cement paste initially known, several tests were performed with different water/cement ratio (W/C) until the report was found giving a sinking of (6 ± 1) mm. The mass of water used for the best ratio was noted M_L.

2.2.2 Setting Time of Cement Paste

Initial setting time was defined as the time elapsed from the instance of adding water to the cement powder until the pastes ceases to behave as fluid or plastic, while final setting time referred to the time required for the cement paste to reach certain state of hardness to sustain some load. The setting period of cementitious materials are often considered as the most important period in the production of cement paste structure [10, 24]. Test has been assessed according to European Norm EN 196-3 [25]. It corresponds to the time water was added on to the cement powder until setting starts. The test was performed to measure the initial and the final setting time at normal consistency. The cement paste was then mixed in the ratio of 0.50 W/C (water/cement ratio). The Vicat's needle of 1.13 mm of diameter and a weight of 300 g was used to determine the initial and final setting time.

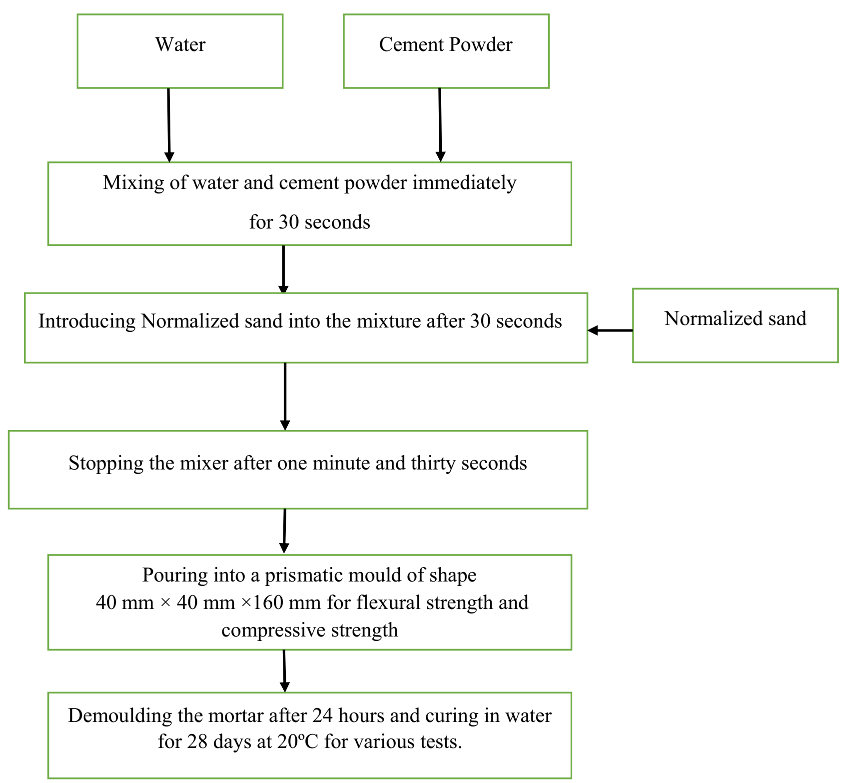

Fig. 2 Experimental protocol for cement mortar

2.2.3 Compressive and Flexural Strength of Mortar

Compressive and flexural test were carried out using the European Norm 196-1:2016 [26] on the prismatic samples produced. Flexural strength was done using the manual press with capacity of 50 kN. Where F_f is the breaking load in N, and R_f is the flexural strength in MPa, l is the distance between the lower support in mm and b the thickness of the specimen ($b = 40$ mm) given as

$$R_f = \frac{1.5 \times F_f \times l}{b^3}. \tag{1}$$

The compressive strength test was carried out on each half of the specimen used for the flexural test at the same dates. The Compressive strength was measured using the relationship (Eq. 2):

$$R_c = \frac{F_c}{S} \text{ or } R_c = \frac{F_c(N)}{1600} \text{ in MPa,} \tag{2}$$

whereby R_c is the compressive strength in MPa, F_c is breaking load in N and $S =$ specimen section in mm^2 ($S = 1600$ mm^2). The compressive and flexural strength test were carried out after 2 days, 7 days and 28 days.

2.2.4 Water Absorption and Apparent Density of Mortar

Measures of water absorption and apparent density analysis of the mortar were carried out according to the norm EN 1015-18:1999 [27] using a mass (m_d). Samples were dried at 105 °C for 48 h in an electric dryer to determine its constant weight and then immersed in a water bath at ambient temperature of 23 °C containing distilled water for 24 h and comparing the humid weight (m_h) to the dry weight (m_d) according to Eq. (3):

$$\text{WA}(\%) = \frac{(m_h - m_d)}{m_d} \times 100. \tag{3}$$

The apparent density (ρ_a) of a sample is defined as the quotient of the dry mass (m_d) of product by the volume occupied by the solid material including the empty spaces found in the grains according to the norm BS EN 14617-1:2013 [28]. The measure of the apparent density is consecutively in the determination of the percentage of water absorption across a balance expressed in Eq. 4 below:

$$\rho_a = \frac{m_d}{V}, \tag{4}$$

$\rho_a =$ apparent density (g/cm^3), $m_d =$ dry mass of sample (g), $V =$ volume of sample (cm^3).

2.2.5 Chemical Analysis of Cement Powder

For chemical analysis, an hXRF Niton XL3t980 analyzer (equipped with an Ag-Anode 50 kV X-ray tube and Silicon-Drift-Detector 8 mm spot was used. The raw data are plotted in a spectra, where the x-axis represent element-specific fluorescence energy (unit keV), and the y-axis quantify counts of photons (unit cps) received by the detector. Detection is possible for most of the elements with atomic numbers ranging from 12 magnesium to 92 (uranium). 21 silicon-based standards so-called Certified Reference Material (CRM), filled in cups and covered with 4 µm polypropylene film were measured by an hXRF device specific mode (mining/mineral mode). The measured values are plotted using a trend line equation and the "fitting coefficient" R^2 (correlation coefficients) are determined. Afterwards, a classification was made according to the quality of the regression line and the distribution of the data. The different types of the Cameroonian Portland cement with their oxides can be used for cement analysis. The use of various formula leads to the obtaining of LSF, SM, AM and the HM.

2.2.5.1 Formula Used in Cement Analysis The formula mostly used in cement analysis are, the lime saturation factor (LSF), silica modulus (SM), alumina modulus (AM) and hydraulic modulus (HM) [29].

Hydraulic modulus:

$$\text{HM} = \frac{\text{CaO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}. \tag{5}$$

Silica ratio or modulus:

$$\text{SM} = \frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}. \tag{6}$$

Alumina ratios or modulus:

$$\text{AM} = \frac{\text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}. \tag{7}$$

Lime saturation factor: (for OPC cement),

$$\text{LSF} = \frac{\text{CaO} - 0.7\text{SO}_3}{2.8\text{SiO}_2 + 1.2\text{Al}_2\text{O}_3 + 0.65\text{Fe}_2\text{O}_3}. \tag{8}$$

2.2.5.2 Bogu's Formula for Cement Constituent Calculation (Alumina Modulus is ˃ 0.64) Based on the results of the chemical analysis and on more or less realistic hypothesis, Bogue (1952) proposed a series of calculations to determine the potential (theoretical) composition of a Portland cement in terms of C_3S, C_2S, C_3A and C_4AF [29–31]. Bogue analyses, therefore, predict the mineralogical phase composition of the cement if its oxides composition is known [29, 30].

$$C_3S = 4.071CaO - \left(7.602SiO_2 + 6.718Al_2O_3 + 1.43Fe_2O_3 + 2.85SO_2\right) \quad (9)$$

$$\begin{aligned} C_2S &= 2.867SiO_2 - 0.7544C_3S, \\ C_3A &= 2.65Al_2O_3 - 1.692Fe_2O_3, \\ C_4AF &= 3.043Fe_2O_3 \end{aligned} \quad (10)$$

2.3 XRD Technique Used in Cement

XRD measurements are performed using a D8 diffractometer equipped with Lynx-eye position sensitive detector (Brucker–AXS), with Cu Kα_1 λ_{Cu} = 1.54056 Å radiation operated at 40 kV and 40 mA, increment 0.013° 2θ, and a measuring time per step of 30 s. The diffraction patterns are collected in the 2 theta range from 7.5° to 70°. Qualitative analysis of the phase composition of the powders was conducted using the PDF-2 2007 release software and X'Pert High Score Plus.

3 Results and Discusion

3.1 Setting Time and Consistency of Cement Paste

The initial setting time for the different cement samples are shown in Fig. 3, while the consistencies are shown in Fig. 4. Cement CM3 present the lowest setting time at 173 min follow by CM4 at 178 min and CM1 at 188 min. Cement CM2 present the highest setting time at 193 min which is Portland pozzolan cement CEM II/A-P 42.5R and CM3 the lowest value of setting time at 173 min which is Portland pozzolan cement CEM II/42.5R.

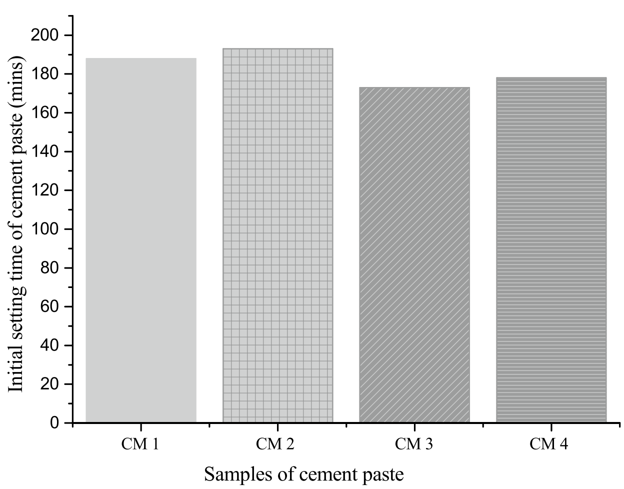

Fig. 3 Initial setting time of cement paste

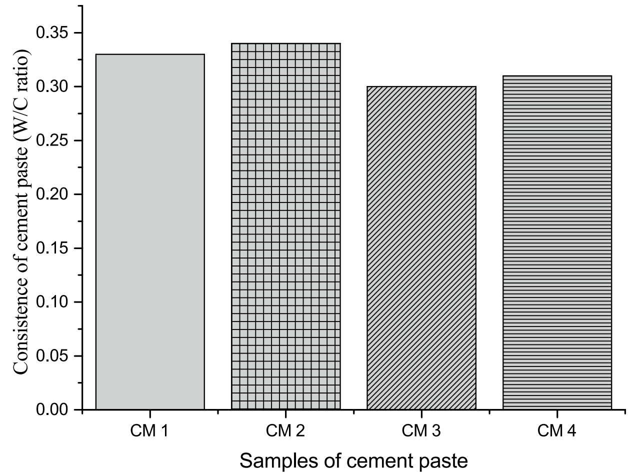

Fig. 4 Consistence of cement

CM2 shows the highest consistency with *W*/*C* ratio of 0.34, followed by CM1 with *W*/*C* ratio of 0.33, CM4 with *W*/*C* ratio of 0.31 and CM3 with *W*/*C* ratio of 0.30, respectively. It is observed that there is no correlation with the initial setting time to the consistency of cement.

Biyindi et al. [30] worked on Dangote and CimenCam cement. Their work proved that CemenCam which correspond to CM2 has the highest and faster setting time of 155 min. While Dangote has a setting time of 200 min. This correspond to our work, whereby CM2 has the initial setting time of 173 min, while Dangote which correspond to CM1, has 188 min.

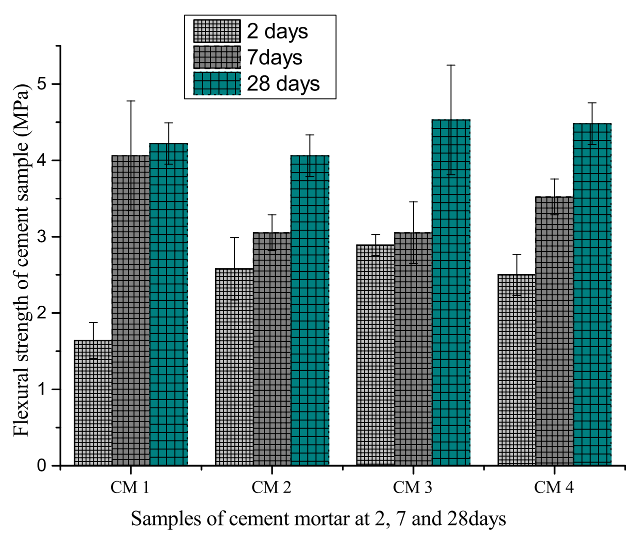

Fig. 5 Flexural strength of cement mortar at 2,7 and 28 days

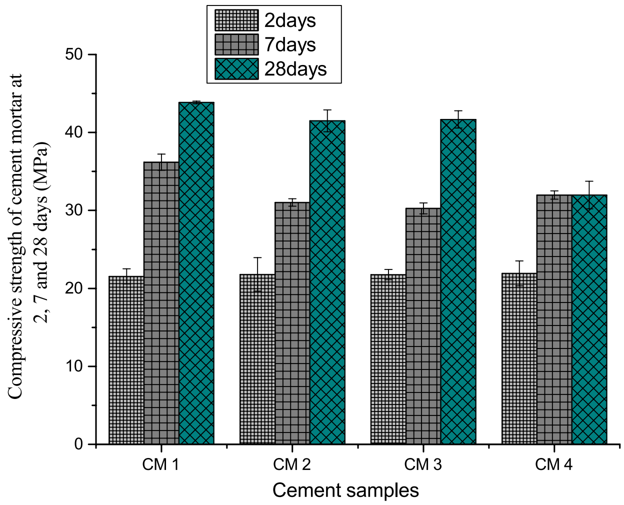

Fig. 6 Compressive strength of cement mortar at 2, 7 and 28 days

3.2 Flexural Strength and Compressive Strength

Flexural strength and compressive strength were carried out on different cement mortar after 2 day, 7 day and 28 day curing, as shown in Figs. 5 and 6, respectively. After 2 day curing, results showed that cement mortar CM3 presents the highest flexural strength of 2.9 MPa, while cement mortar CM2 present 2.6 MPa, cement mortar CM4 present 2.5 MPa and cement mortar CM1 present 1.6 MPa, respectively. After 7 days of curing, CM1 present the highest flexural strength of 4.1 MPa, while CM2, CM3 and CM4 present 3.1 MPa, 3.1 MPa and 3.5 MPa respevtively. After 28 day curing, cement mortar CM4 present the highest flexural strength of 4.8 MPa, while CM3, CM1 and CM2 present, respectively, 4.7 MPa, 4.2 MPa and 4.1 MPa. For flexural strength, the standard deviation presented in Fig. 5 is between 0.1 and 0.4 at 2 days, and between 0.2 and 0.7 from 7 to 28 days. Explaining that the results observed are very accurate at early age of cement hydration. Table 1 presents the results of compressive strength of cement mortar and their corresponding initial setting times. At 2 day curing, there is no great difference in compressive strength of the various cement mortar samples but at 7 day curing, CM1 shows a higher strength of 36.2 MPa followed by CM4 with 32.0 MPa, and CM2 with 31.0 MPa, while CM3 presents the lowest value at 30.3 MPa. At 28 day curing, compressive strength of cement mortar of CM1 was 43.9 MPa and CM4 43.8 MPa, while cement mortar CM2 and CM3 present the lowest value of compressive strength at 41.4 MPa and 41.7 MPa, respectively. The cement CM2 and CM3 have values slightly below the range of 42.5 MPa which are 41.4 MPa and 41.8 MPa, respectively. For compressive strength, the standard deviation presented in Fig. 6 is between 0.6 and 2.1 at 2 day, and between 0.4 and 1.0 at 7 days and at 28 days, is between 0.1 and 1.7. Explaining that the results observed are accurate at different age of cement mortar hydration. From the results of compressive and flexural strength cement mortar CM4 which is a belite cement presents the best mechanical strength at 28 days. Similar work was done on different cement concrete produced in Nigeria on the investigation of a serie of test on strength characteristics, where compressive strength from Dangote after 28 days was 21 MPa [32]. This work is on line but lower than our work with the Dangote cement mortar showing the highest compressive strength of 43.9 MPa at 28 days.

Table 1 Compressive strength of cement mortar and their corresponding initial setting time

Compressive strength of cement mortar (MPa)					Setting time of cement paste (min)
Class 42.5R Norm EN 196-1	At early strength ≥ 20 (18)		Standard strength		(Min) ≥ 60 Norm EN 196-3
			Min ≥ 42.5 (40)	Maxi ≥ 62.5	
	2 days	7 days	28 days		
CM1	21.5	36.2	43.9		188
CM2	21.8	31.0	41.4		193
CM3	21.8	30.3	41.8		173
CM4	21.9	32.0	43.8		178

3.3 Water Absorption and Apparent Density of Cement Mortar

The water absorption was assessed after curing the cement mortar samples for 28 days. The results are shown in Fig. 7. Cement mortar CM1 present a higher percentage of water absorption of 2.35 wt% as compare to the other cement

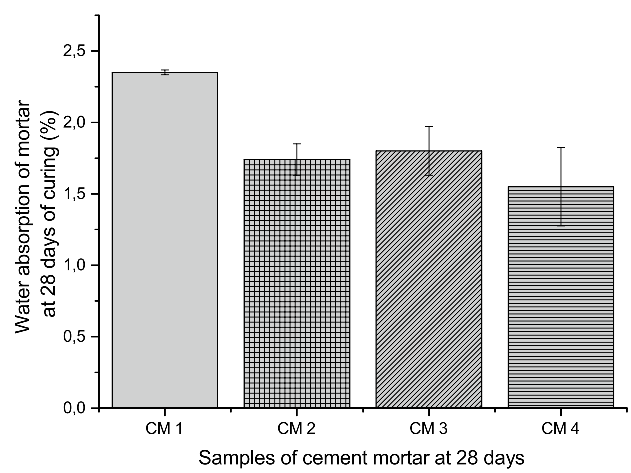

Fig. 7 Water absorption of mortar at 28 day curing

mortar. CM3, CM2 and CM4 with respectives values as 1.80 wt%, 1.74 wt%, and 1.56 wt%. The standard deviation in Fig. 7 calculated from water absorption measured from different cement mortar at 28 day curing varying between 0.01 and 0.27 explaining that the results are very accurate. Water absorption measure the capillary movement of water in open pores of mortar. It's also give an idea on the accessibility of pores. Water absorption gives an idea of porosity on the hard paste mixture and the empty spaces that are present in the granulate at two levels: on mecanical strength and durability of the mortar. Results of apparent density are shown in Fig. 8. It presents cement mortar CM1, CM2, CM3 which show approximatly the same value at 2.17 g/cm^3, while CM4 shows the lowest value of density at 1.55 g/cm^3. The standard deviation for apparent density in Fig. 8 of different cement mortar at 28 day curing varying between 0.007 and 0.017 explaining that the results are very accurate. CM4 with the lowest value of water absorption at 1.56 wt% and the lowest value of density at 1.55 g/cm^3 is justified by the lower value of *W*/*C* ratio at 0.31 in the cement mortar.

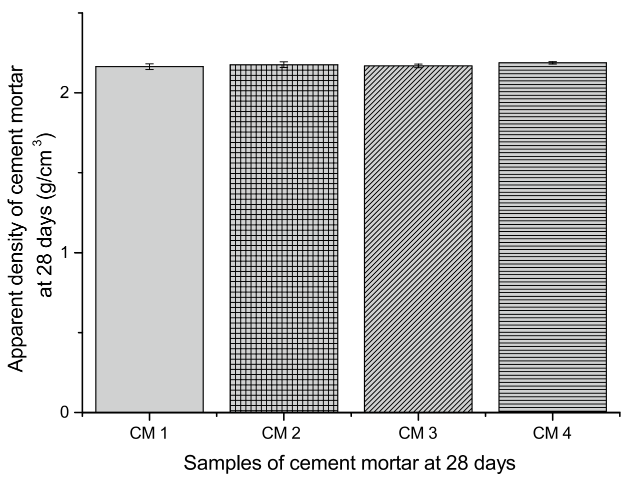

Fig. 8 Apparent Density of mortar at 28 days

3.4 Effect of Various Factors on Cement

3.4.1 Lime Saturation Factor (LSF) of Cement

Lime saturation factor expresses the maximum amount of lime that can be combined with the various oxides present, based on the chemical formula of cement C_3S (tricalcium silicate), C_2S (dicalcium silicate), C_3A (tricalcium aluminate), and C_4AF (tetracalcium alumino-ferrite) [29]. It also controls the ratio of Alite and Belite in the cement calculated from the chemical composition, as shown in Table 2. Lime saturation factor has a typical range value of 0.66–1.02. CM1, CM2, CM3 and CM4 has LSF values of 0.98, 0.61, 0.74, and 0.73, respectively. LSF is higher for CM1 which was Portland limestone cement CEM II/A-P 42.5R, while Portland pozzolanic cements CM3 and CM4 present lower values of LSF and CM2 has value slightly lower than the limited range values 0.66–1.02. This higher value of LSF for CM1 indicates the presence of more silica in the cement and less alumina and iron oxide. Lower values of LSF leads to a reduction of the theoretical heat and also a reduction of CO_2, when burning for preparing or manufacturing the cement. From Bogu's formula, the cement CM2 is expressed as alite–belite cement. CM2 with the lowest value of LSF also present the highest value of Al_2O_3 which is 4.90 wt%, as shown in Table 3, and the lower value of Sulphur which is 4.13 wt%. This high value of alumina and lower value of Sulphur can be explained by the fact that, it reduces humidity in building environment than CM1, CM3 and CM4. The humidity in the cement is mostly hydrated to calcium sulfite hydrate and this is reduced by the presence of alumina and

Table 3 Calculation factor for different cement

Ratios	Cement				
	CM1	CM2	CM3	CM4	Typical range
LSF	0.98	0.61	0.74	0.73	0.66–1.02
SR	3.29	2.83	3.38	3.57	1.8–2.7
AR	1.34	1.03	0.91	0.80	1.0–1.7
Na_2O	0.63	0.60	0.51	0.51	$<$0.9
HM	2.48	1.41	1.88	1.88	1.7–2.3

Table 2 Chemical composition and specific surface area of cement powder

Sample	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	NiO	P_2O_5	PbO	SO_2	SiO_2	TiO_2	ZrO_2	H_2O	Total	Specific surface area g/m^2
CM I	3.34	0.04	62.23	0.01	2.50	0.95	0.00	0.01	0.00	0.01	5.01	19.22	0.33	0.09	2.50	96.25	1.26
CM II	4.90	0.04	52.18	0.02	4.75	0.91	0.00	0.01	0.17	0.00	4.13	27.36	0.81	0.12	2.60	98.01	1.51
CM III	3.40	0.04	58.84	0.02	3.74	0.78	0.00	0.01	0.00	0.00	4.92	24.14	0.46	0.08	2.80	99.24	1.08
CM IV	3.03	0.05	58.69	0.01	3.78	0.79	0.00	0.02	0.00	0.00	4.88	24.35	0.46	0.08	2.60	98.74	1.44

iron to form stable hydrates (mono-sulfates etc.). The cement CM1 has higher values of LSF of 0.98 and from Bogu's formula CM1 is Alite cement. Alite (C_3S) is the most important constituent in cement and it is responsible for the early setting characteristics and development of the early strength of cement at 7 days and 28 days. Alite has a relatively more defective crystal structure than belite; this is primarily attributed to the observation that in alite crystals, the spaces in the crystals structure that were supposed to be occupied by oxygen are unfilled; this allows water to start reactivity with alite faster [33]:

$$CaO + 2CaO\,SiO_2 = 3CaO \cdot SiO_2(C_3S)\ \text{Alite}1848.1\ \text{kJ/kg.}\,[31] \tag{11}$$

CM1 with higher values of LSF contains lower values of alumina at 3.34% and higher value of Sulphur at 5.01%. This can be explain by the fact that the excess of sulfur can produce $CaSO_4 \bullet xH_2O$ which can enhance humidity in building environment, but the lower values of Fe_2O_3 at 2.5 wt% means that the cement is predispose to resist corrosion of iron armature in humid environment. The cements CM3 and CM4 has the LSF of 0.74 and 0.73, respectively; this two cements are belite cement. The quantity of alite is lower with respective values of 13.82 and 14.14 from the literature; belite cement reacts slowly with water, thus contributing little to the strength during the first 28 days [19, 29–32]. The relative more perfect crystalline structure of belite renders it less reactive [33]:

$$2CaO + SiO_2 = 2CaO \cdot SiO_2(C_2S)\ \text{Belite}1336.81\ \text{kJ/kg.}[31] \tag{12}$$

Belite cement is produced with a lower theoretical heat when manufacturing [31]. They are regarded as environmentally friendly, because their manufacture consumes less energy than the conventional processes [31]. The alumina content in belite cement CM3 and CM4 are 3.4% and 3.0%, respectively, while sulphur shows higher values of 4.92% and 4.88%, respectively. Its sensibility in humid environment is mostly affected by calcium sulfate hydrates. The iron oxides for CM3 and CM4 are 3.4% and 3.78%, respectively, higher than CM1 and lower than CM2. Alite and belite determine most of the adhesive properties, strength and durability of Portland cement [32].

3.4.2 Silica Modulus (SM) of Cement

The silica modulus, was referred to as the ratio of silica to alumina and iron oxide. For a given LSF, the higher the silica modulus, the more C_3S is produced and the less C_3A and C_4AF will be produced. This can be expressed from cement calculation and the Bogu's calculation. The LSF from cement calculation of CM1 is 0.98, while the silica modulus is 3.29 very far from the range of 1.8–2.7. The values of C_3S (66.73) is by far higher than C_3A (4.62) and C_4AF (7.6). The silica modulus of the cement governs the proportion of silicate phase in the cement. The silica modulus of cement powder for CM1, CM2, CM3 and CM4 are 3.29, 2.83, 3.38 and 3.57, respectively. CM1, CM3 and CM4 present values higher than those within the limited range. While CM2 with value of 2.83 is slightly close to the limit range. CM2 with the value slightly close to the limit range has the highest value of SiO_2 at 27.36%, while SO_2 is 4.13%. In CM2, Al_2O_3 presents the highest value at 4.90% and the highest value of Fe_2O_3 at 4.75%. The high value of alumina will reduce humidity in the building, while at the same time, the higher values of iron oxides cause corrosion of the iron armature in humid building environments.

3.4.3 Alumina Modulus (AM) of Cement

The alumina modulus of cement is the ratio of alumina to ferrite phase in the cement for ordinary Portland cement. These values of Alumina Modulus for CM1, CM2, CM3 and CM4 are 1.34, 1.03, 0.91 and 0.80, respectively. Alumina modulus for CM1 and CM2 are in the range 1.0–1.70. While alumina ratio for CM3 and CM4 are lower and below the range. Aluminate contributes slightly for early strength development and C_3A hydrates very rapidly and will influence early bonding characteristics (Eqs. 13 and 14) [33]:

$$3CaO + Al_2O_3 = 3CaO \cdot Al_2O_3(C_3A)\ \text{aluminate} \tag{13}$$

$$3CaO \cdot Al_2O_3 + 6\,H_2O = 3CaO \cdot Al_2O_3 \cdot 6H_2O. \tag{14}$$

3.4.4 Hydraulic Modulus (HM) of Cement

Hydraulic modulus for CM1, CM2, CM3 and CM4 are, respectively, 2.48, 1.40, 1.88 and 1.88. CM3 and CM4 present the same hydraulic modulus values of 1.88. However, CM1 have a hydraulic modulus out of the range limit1.70–2.30. The hydraulic modulus of CM1 is very higher than the other cements and can be classified in the order of CM1 > CM3 and CM4 > CM2.

Table 4 Bogu's calculation for cement components

Cement component	CM1	CM2	CM3	CM4
C_3S	66.73	47.03	13.82	14.14
C_2S	4.76	42.96	58.79	59.14
C_3A	4.62	4.95	2.68	1.63
C_4AF	7.6	14.45	11.38	11.50

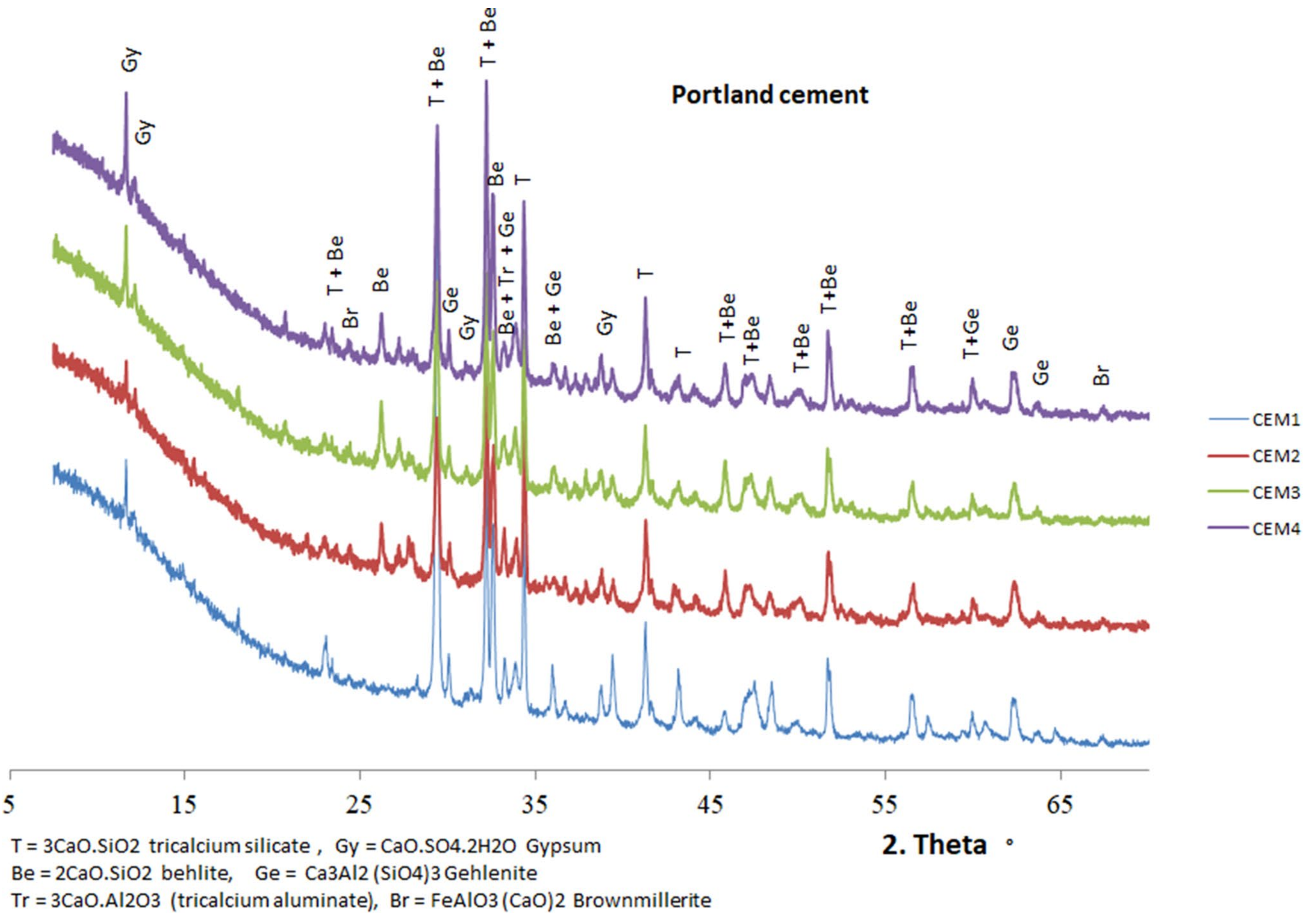

Fig. 9 XRD of cement powder

3.4.5 Mineralogy of Cameroonian Portland Cement

Results obtain from Bogu's calculation are shown in Table 4 and are in correlation with results obtain from the XRD diffractogram shown in Fig. 9. The XRD diffractogram of different Cameroonian Portland cement shows the mineralogical composition of various components found in four cement. The components found in the cement were: alite, belite, Celite, gypsum, gehlenite and brownmillerite. Gypsum is also present in a small quantity in all the various Portland cement. Gypsum in the form of hydrated calcium sulfate ($CaO•SO_4•2H_2O$) regularize the hydration kinetic of cement at early age. Gypsum plays a very important role in the hardening of cement. The presence of gypsum in cement compounds helps to improve the initial setting time of the cement [29, 34]. In fact, alite and Celite react very rapidly in cement and the presence of gypsum regularize the kinetic of hydration at early age. This justifies the reason for the presence of gypsum in different types of Cameroonian Portland cement characterized.

For CM1 cement the alite (C_3S) peak is very higher than the other cement CM2, CM3 and CM4. The peak attributed to belite is very small and the belite peak is increased in CM2, CM3 and CM4. There are similarities with XRD diffractogram and Bogu's formula. The presence of alite for CM1 on XRD diagram was also present and was also confirmed on the Bogu's formula for CM1. The low brownmillerite content in CM1 is due to the low quantity of iron oxide about 2.5% obtained from the chemical composition of cement.

From the XRD diffractogram, the belite (C_2S) peak is shown in different cement and the presence of belite is in the order of CM4 ˃ CM3 ˃ CM2 ˃ CM1 which correspond to Bogu's formula calculation. The presence of alite and belite on XRD diffractogram of CM2 correspond to the alite–belite-type cement. Alite react rapidly with water and is responsible for early strength development of cement mortar CM1. Belite is less reactive at early age but contribute to strength at later ages, as shown in Figs. 5 and 6, for CM3 and CM4. The brownmillerite (C_4AF) is present in all type of cement but the peak intensity of CM2 is very higher than CM3, CM4 and CM1. The presence of C_4AF in cement is assimilated to the quantity of iron oxide present in the cement, thus the excess of iron oxide in cement cause expansion and cracking of the cement paste [32–34]. The Celite (C_3A) present on the XRD diffractogram are in different cement and the peak intensity corresponds to the quantity of alumina in the cement, the Celite is in the order of CM2 > CM1 > CM3 > CM4.

3.4.6 Correlation Between Mechanical Properties and Cements Factors

At 2 days of curing, CM1, CM2, CM3 and CM 4 shows lower values of flexural strength as 1.6, 2.6, 2.9, and 2.5 MPa, respectively, as compared to values obtained at 28 days of curing. CM1 shows the lowest flexural strength of 1.6 MPa, while CM3 has the highest flexural strength of 2.9 MPa. The reason for CM1 showing the lowest flexural strength was due to the high value of LSF of 0.98 obtained and also the high value of hydraulic modulus of 2.48. The high value of CM3 was due to the SR value of 3.38 which is above the range value and it also has a lower value of equivalent sodium oxide as 0.51, while AR value is higher for CM3 as 0.91. LSF and AR are within the range limit. At 28 days, CM2 show the lowest value of flexural strength. It contains lower values of LSF of 0.61 and HM of 1.41but CM4 has a high value of flexural strength of 4.8 MPa and the LSF and HM are within the range limits.

At 2 day curing, compressive strength for cement mortar CM1 and CM2 are almost the same but at 7 days of age, CM1 which is an alite cement gives the highest value of compressive strength of 36.2 MPa, CM2, CM3 and CM4 which present values of 31.0 MPa, 30.3 MPa and 32.0 MPa, respectively. This higher value of CM1 at 7 days can be justified by higher values of LSF and HM. At 28 days of compressive strength CM1 and CM4 have the highest values of compressive strength of 43.9 MPa and 43.8 MPa, respectively. As for CM3 and CM2, present lower values of 41.8 MPa and 41.4 MPa below the range, respectively. The lower compressive strength of CM2 is due to the lower values of LSF as 0.61 and is slightly within the range limit.

3.4.7 Correlation Between Mechanical Properties and Bogu's Calculation

CM1 has the lowest value of flexural strength at 2 day curing. This is because it has lower values of C_3A and C_2S but higher values of C_3S. At 28 day curing, CM2 has lowest value of flexural strength at 4.1 MPa corresponding with highest value of C_4AF of 14.45 and C_3A of 4.95 which is an alite–belite cement. CM1 has the highest value of C_3S, and high value of C_3A. At 2 day curing, there is no significant difference in the compressive strength, but at 28 day curing, the compressive strength of CM1 and CM4 are nearly the same.CM1 is characterized by an alite cement with lower values of C_4AF as 7.6 and CM4 is belite cement with high value of C_4AF and lowest value of C_3A of 1.63 but CM2 and CM3 at 2 days present the same compressive strength, thus CM2 is identified as alite–belite cement and belite cement for CM3, respectively. From Bogu's formula, alite cement reacts very rapidly than belite cement but results shows that at 28 days of compressive strength, CM2 and CM3 shows compressive strength of 41.1 MPa and 41.8 MPa, respectively. Flexural strength of belite cement at 28 day curing was higher than alite cement and later higher than alite–belite cement. Belite cement are characterized by low values of LSF and are produced at low temperature. They show slow rate of hydration and lower reactivity [34–37]. Galyna et al., [38] works showed that to increase the reactivity of belite cement, calcium aluminate and ferrites could be used which in turn reacts faster with water to form the crystallization nuclei of the ettringite.

Alite cement can be favourable in humid areas due to the formation of high amount of calcium hydroxide which maintains higher PH at which embedded reinforced steel is maintained in a passivated state thereby preventing corrosion. While belite cement can be favourable in arid areas due to lower calcium hydroxide produced.

3.4.8 Correlation of Specific Surface of Cement and Mechanical Strength

It is known that the quality and type of cement are significant factors to determine the strength development of concrete, which is specifically affected by the fineness and mineral composition of cement [38–40]. Fineness of cement leads to rapid development of strength and also the appropriate distribution of fine particles of cement contribute to the decrease of heat of hydration [38–40].The specific surface area of CM1, CM2, CM3 and CM4 are 1.26, 1.51, 1.08 and 1.44 g/cm^{2,} respectively. CM3 has the lowest specific surface area of 1.08 g/cm^2 and the lowest setting time of 173 min, while CM2 has the highest specific surface area of 1.51 g/cm^2 and highest setting time of 193 min. The setting time does not depend on the specific surface area of the cement powder. Results obtains from Table 3 shows that the setting time of the various cements are not linked to their specific surface area, but depend on the chemical and mineralogical composition of cement. The high specific surface area of CM2 is due to the presence of smaller particle size of the cement. The greater the surface area to volume ratio the more available space for water to cement (*W*/*C*) reaction to take place per unit volume. At early strength of 2 days, CM3 shows the highest flexural strength development of 2.9 MPa.

At 2 day curing, the compressive strength of CM2 and CM3 both shows lower values of 21.8 MPa which are close together but at age of 28 days, CM2 41.4 and CM3 41.8 MPa values are different. This can be attributed to the fact that since CM3 is a belite compound, it has a slow rate of hydration and lower reactivity but CM2 has a larger amount of hydration products, a loose microstructure that develops at early age, a relatively high water requirement and low packing density. This can lead to relatively low values of flexural strength at 28 days.

The alite cement CM1 and belite cement CM4 gives a better mechanical strength in tropical region.

3.4.9 Correlation Between Density of Cement Mortar and Specific Surface of Cement

The samples CM1, CM2, CM3 and CM4 shows the apparent density of 2.16, 2.18, 2.17 and 1.55 g/cm^{3,} respectively, while their specific surface areas for CM1, CM2, CM3 and CM 4 are 1.26, 1.51, 1.08 and 1.44 g/cm^2.

The specific surface area could be defined as a geometrical parameter which is important in Characterizing raw material mixtures and this parameter affects the efficiency of grinding operations, classification and homogenization of the raw materials [39, 40].

The highest values for apparent density can be due to the fact that they exhibit higher content of fine particles and the fine particles can ideally fill the voids between large particles, thus enhancing the packing density of powder materials [41–46]. CM2 show the highest specific surface of 1.5 g/cm^2 and also the highest initial setting time of 193 min. This higher setting time might be influenced by the finess of the cement; the chemical composition and the ambient temeperature but in this way initial setting time is faster not for cement finess but for cement composition.

4 Conclusion

The engineering properties focus on comparative studies: mechanical, hydraulical and mineralogical characteristic of Cameroonian portland cement sold in the market. It can be concluded that CM2 has the highest consistency of 0.34 and an initial setting time of 193 min as compared to CM1 with 0.33, CM4 with 0.31 and CM3 with 0.30 *W/C* ratio, respectively. The flexural strength and compressive strength obtained after 28 days were given for CM4 as 4.8 MPa and 43.8 MPa, CM3 as 4.7 MPa and 41.8 MPa, CM2 as 4.1 MPa and 41.4 MPa and CM1 as 4.2 MPa and 43.9 MPa, respectively. The compressive strength depends on the mineralogical composition of cement, the water/cement ratio and hydraulic modulus of cement. The water absorption and apparent density given of CM1, CM2, CM3 and CM4 were 2.35 wt% and 2.16 g/cm^3, 1.74 wt% and 2.18 g/cm^3, 1.80 wt% and 2.16 g/cm^3 and 1.55 wt% and 1.55 g/cm^{3,} respectively, and with CM1 having the highest value of water absorption. The calculation factor shows that, CM1 is an Alite cement, CM2 is an alite–belite cement, CM3 and CM4 are Belite cement.

Lime saturation factor has a typical range value of 0.66–1.02. CM1, CM2, CM3 and CM4 have LSF of 0.98, 0.61, 0.74, and 0.73, respectively. It's known that lower values of LSF leads to a reduction of the theoretical heat and also a reduction of CO_2 when burning, preparing or manufacturing the cement. The high value of alumina and lower value of Sulphur can be explained by the fact that, it reduces humidity in building environment The humidity are mostly formed by calcium sulfite hydrate and this is reduced by the presence of alumina and iron to form stable hydrates (mono-sulfates etc.). The high value of alumina for CM2 will reduce humidity in the building but the high values of iron oxides might cause the corrosion of the armature in humid buildings environments and this cement is favourable in arid region. Alite cement can be favourable for building and road construction in humid areas due to the formation of high amount of calcium hydroxide which maintains higher PH at which embedded reinforced steel is maintained in a passivated state thereby preventing corrosion. While belite cement can be favourable for building and road construction in arid areas due to lower calcium hydroxide produced.

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Declarations

Conflict of interest The authors declare that there are no conflicts of interest.

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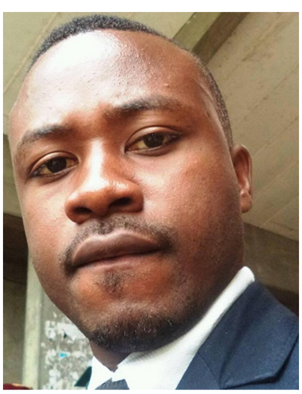

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