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Study Of The Mechanical Properties Of Metakaolin Concrete Based On The Partial Substitution Of Cement In A Reference Concrete By Halloysite Clay From Balengou In West Cameroon

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Abstract:
The present work focuses on the study of the mechanical properties of metakaolin concrete (MKC) based on the partial substitution of cement in a reference concrete by Balengou halloysite clay in West Cameroon. The clay heat treatment test, the particle size analysis test of the aggregates used, the water content test, the sand equivalent test, the specific gravity and bulk density test, the mix design of the reference concrete by the Dreux - Gorisse method, the mix design of metakaolin concrete with partial substitution of the cement in the reference concrete by 0, 10, 20, 30 and 40% of halloysite clay from Balengou namely $MKC_{0\%}$ $MC_{10\%}$ $MKC_{20\%}$ $MKC_{30\%}$ and $MKC_{40\%}$. The results obtained were impressive with 21.20 MPa and 1.87 MPa at 7 days for $MKC_{20\%}$ in compression and tension respectively, 30.65 MPa and 2.44 MPa at 28 days for $MKC_{40\ \%}$ in compression and tension respectively. The finding here showed that the mechanical strengths are greater than the characteristic values 25 MPa and 2.1 MPa in compression and in tension at 28 days targeted during the design of mix.

Keywords: *Halloysite clay; partial substitution of cement, Design of metakaolin concrete, mechanical strengths.*

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I. Introduction

1.1. Generalities

The construction industry is a particular emitter of greenhouse gases and, in particular, of CO_2 released during the manufacture of Portland cement. To limit these releases, with equivalent concrete performance, it is possible to replace part of the cement by some additions, either directly at the cement plant, or, for some only, in a concrete batching plant during the production of concrete. Among these additions, natural and artificial pozzolanas hold a special place.

Indeed, since the Roman Pantheon almost 2000 years ago, natural or artificial pozzolanas have been used regularly in constructions. These products are thus included in the composition of certain industrial cements (EN 197-1) as main constituents: this is the case of cement (CPJ-CEM II) or pozzolanic cement (CEM IV). The ASTM 618 Standard on cement indicates that a pozzolana is a siliceous, aluminous or ferruginous material, having little or no binding properties in itself, but, when finely ground and in the presence of water, can react chemically with calcium hydroxide ($Ca(OH)_2$) at ordinary temperature and pressure to form a binder. This definition requires the study of the structure and chemical composition of the material if we want to assess its pozzolanic property (Tchamo, 2014).

Clay refers to any natural material composed of fine grains, which turns plastic in the presence of appropriate water contents and hardens by drying or heating. Plasticity is the ability of the material to acquire and retain any possible shape during shaping. The clay particles are more or less hydrated aluminosilicates whose structure consists of a stacking of sheets. In its natural state, the pozzolanic activity of halloysite clay is low, but heat treatment greatly improves this property. The exploitation of chemical, radiocrystallographic and differential thermal analysis results shows that Balengou clay is essentially made up of Halloysite (70%). An enrichment by particle size classification brings this content to 90% in the particle size fraction of less than 2 microns metre (Njopwouo D., 2011). Heat treatment of Balengou halloysite clay at 750 ° C gives metakaolinite (MK).

The use of Metakaolin in the concrete has received considerable attention in recent years due to its high pozzolanic reactivity and improvement of long-term durability. Until now, it is not possible to take it into account as a substitute of cement in the design in the sense of European standard NF EN 206 / CN 2014).

1.2. Problem Statement

The studies of clays have been part of the major projects of the Local Materials Promotion Authority (MIPROMALO Yaounde) since the creation in 1990 (Ngon, 2005). Such studies have led to the use of clays as building materials and in the manufacture of ceramics. The present work is part of the development of local natural resources, more particularly, prospecting the possibility for the use of halloysite clay, which is abundant in the locality of Tsila, village of Balengou, town of Bazou, Division of Nde, in West Region of Cameroon, in the concrete industry. The particularity of this work lies in the fact that it will not be limited to the evaluation of the pozzolanic reactivity of metakaolin obtained by heat treatment of halloysite clay at 750 ° C, but also to the ability of its use as a partial substitute of cement in concrete.

1.3. Research interest

The interest of our study is to reduce the quantity of cement used in manufacture concrete, by using halloysite clay local material. This reduction in cement consumption has advantage of lower construction cost and protection of the environment.

1.4. Research objective

The main objective of the present work is the study of the mechanical properties of metakaolin concrete (MKC) based on the partial substitution of cement in a reference concrete with Balengou halloysite clay in West Cameroon.

II. Literature Review

Knowledge and mastery of the natural setting of the study area are important elements that go into the genesis and exploitation of weathering products.

Colluvial / alluvial soils are found throughout the study area and are observed at the foot of the slope. These materials from the surrounding hills accumulate to form multi-colored soil types that have a very clayey texture.

The natural clay is first dried at room temperature and then ground for a long time in a G91 type ball mill. It is important to grind the material well and to sieve at 2µm (Day et al., 1994; Shi., 2001). This clay will then be placed in the oven to undergo the heat treatment.

The heat treatment of the clay consisted of its calcination in an electric furnace. This oven heated to a temperature of 750 ° C creates excitement within the material. It is this disorder that makes the material more reactive hence it becomes pozzolanic (Bich et al., 2009; Elimbi et al., 2011; Rashad, 2013). The thermal activation of halloysite clays has been widely studied for use in cementitious materials. Several studies can be found in the literature that have studied the thermal activation temperature of clays as well as the activation time.

Clay materials are obtained after alteration of rock masses subjected to certain specific conditions. These clay materials are weathering products rich in mineralogical and textural clays (Djichout, 2013). Clay materials are part of many non-metallic mineral resources that are abundant in Cameroon. Since the first civilizations, these materials have been used both in industrial and artisanal ceramics (pottery, bricks, tiles, tiles, porcelain, earthenware, dental prostheses, filters, electronic components, etc.) and in the chemical industries (oil mills, pharmacies, cosmetics , rubber) (Njopwouo, 1984; Nkoumbou et al., 2001; Njiomou, 2007; Ben et al., 2011). These varieties of applications are due to the multiple properties that these materials possess. These include malleability in the presence of water, hardening after firing or the ability to fix alkali metals in the presence of water at room temperature to form new compounds, stable, poorly soluble in water and possessing binding properties. This last property is called pozzolanic power and refers to all the processes which transform mixtures of materials and lime into hard and compact buildings at room temperature (Sersale, 1980; Melo and Ndigui, 2005).

There is increasing interest in the use of clay materials, especially those rich in SiO_2 and Al_2O_3, in the manufacture of hydraulic and geopolymer cements (Davidovitss, 1991; Boutterin and Davidovits, 2003; Komnitsas and Zaharaki, 2007; Elimbi et al. 2011). However, attention is paid less to the structural characteristics of the starting materials than to the conditions of amorphization and the behavior of the amorphous phase obtained during the various stages of cement manufacturing (Murat et al., 1982; Bachiorrini, 1982; Ambroise, 1984; Njopwouo, 1984; Elimbi et al., 2011; Tchakouté et al., 2013). The challenge of optimizing the compositions and the process required for the manufacture of products with satisfactory use characteristics conceded to minimum production also involves the availability and mastery of the characteristics of raw materials. In Cameroon context, the development of local resources as a contribution to sustainable development is a permanent political concern. Crystallinity is one of the structural parameters which influence the pozzolanic power of a material, it depends on the arrangement of the elementary layers within the clay mineral (Kakali et al., 2001; Bich et al., 2009; Rachigo et al., 2009; Rachigo et al. al., 2011; Fabbri et al., 2012).

Alteration is the set of phenomena that cause rock furnishings at the continental interface, that is to say in contact with two sets comprising on the one hand the constituent elements of the atmosphere, the hydrosphere and the biosphere and on the other hand, those of the lithosphere (Ekodeck and Kamgang, 2003).

The passage of rock from a solid state to a loose state setting up the evolutionary sequence of materials involves three fundamental processes: bisiallitization, monosiallitization and allitization (Pedro and Delmas, 1971). The differentiations of a textural, structural and mineralogical order which intervene during the weathering processes are produced by two groups of antagonistic mechanisms namely: the subtraction mechanisms, which proceed by leaching of the most mobile constituents and the addition mechanisms which proceed by migration of the less mobile constituents (Bonneau and Souchier, 1979). Two aspects of chemical weathering can be distinguished: geochemical weathering and biochemical weathering (Pedro, 1978). Geochemical alteration has certain characteristics, the most important of which is manifested by solubilization of the mineral constituents of rocks. This solubilization takes place by chemical reactions, mainly hydrolysis which manifests itself by: (1) the destruction of the structure of the parent mineral with release of cations and silica, (2) the departure in solution or in suspension of part of the elements released and (3) the recombination of the residual elements in new mineral phases (neogenesis) which evolve very quickly towards simple crystalline forms (oxides) or complex (clay).

The stable weathering products of rocks individualize in the surface environment. In the case of alumino-silicate rocks, it leads to the genesis of secondary minerals built up from a planar layer of aluminum hydroxide called “octahedral layer”, which can be alone or associated with one or two layers of aluminum. silicon oxide called "tetrahedral layer".

The tetrahedral layer is formed of SiO_4 tetrahedra bonded to each other in a plane, with a silicon atom in the center surrounded by O_2 and the octahedral layer, formed each of the octahedra having at its center a trivalent or divalent cation, surrounded by a group hydroxyl (OH-). (DJICHOU NEMBOT Vitalice; 2013).

Most clays and minerals come from the transformation of primary silicates or volcanic (granitic) rocks, under the influence of physical and chemical processes involving water from the surface of the earth's crust.

Some substances, when dissolved in water, increase the acidity of the water, thereby accelerating the decomposition of primary minerals. Helgeson and Mackenzie have shown that the dissolution of atmospheric carbon dioxide can, upon hydrolysis, triple the rates of K-feldspars decomposition and halloysite formation. If the drainage of these rocks by water is abundant, this natural geochemical process leads directly to the formation of halloysite.

Primary clays can be carried away by runoff water, they then mix with the sand and settle in pits. They then constitute the so-called secondary or sedimentary halloysites. (Rabehi, 2013).

Moundom et al. (2016) carried out the physical characterization of black volcanic ash from Baïgom, black pozzolanas from Ngouogouo and brown pozzolanas from Mfosset in the locality of Foumbot. For Baïgom sands, the fineness modulus is 2.09 and the sand equivalent is 78.9%; For the Ngouogouo sands, the fineness modulus is 4.21 and the sand equivalent is 96.1% and for the Mfosset sands, the fineness modulus is 4.07 and the sand equivalent is 95.8 %.

Moundom et al. (2018) carried out the mechanical properties of lightweight concretes made from granular volcanic materials from the locality of Foumbot and proposition for their use in construction. The compressive strengths at 28 days varied between 3.87 and 8.26 MPa.

Billong et al. (2013) determined the absolute density and the particle size analysis of powders of three pozzolan samples from Ngouogouo and Fossang in the locality of Foumbot in West Cameroon and Djoungo in the Littoral with dimension less than 100 µm and found respectively of 2.915, 3.013 and 2. 872 g / cm^3.

According to standard NF P 18-541, it is desirable that the fineness modulus of concrete sand should be between 2.2 and 2.8. Otherwise the sand is fine if the fineness modulus is less than 2.2 or coarse if the fineness modulus greater than 2.8. It should be noted that coarser sand may lead to poorer workability with possible segregation and with increase of compressive strength on one hand and that on the other hand, finer sand can reduce the strength of the concrete while facilitating workability. However, it is possible to correct a sand. This involves modifying its fineness modulus by adding another sand of a different fineness modulus to obtain a sand of the desired fineness modulus between 2.2 and 2.8. For this correction, the proportions of different sands (in absolute volumes) are determined by the Abrams rule.

Mbessa et al. (2012) proposed a composition of concrete and mortar from Sanaga sand 0/5, gravel 12.5 / 16 from Nkometou in Lékié, Pozzolana from Djoungo crushed into powder and used as a partial substitute of Cimencam's CPJ 35 cement in the mixture. The work also determined the variation of the compressive strength of the concretes and mortars manufactured as a function of partial replacement of the cement by the pozzolana powder. The compressive strengths varied from 12.13 to 0.96 MPa for concrete and from 4.36 to 0.65 MPa for mortars.

According to the abovementioned works, the physical, chemical, mineralogical and pozzolanic properties of Balengou clay were determined without information on its use as a partial or total substitute for cement in the manufacture of concrete or cement mortars, hence the interest of this work.

III. Materials And Methods

3.1. Location of the study area

Balengou is located 25 km from Bagangte on the Bagangte-Bafang national road and 6 km to the Northwest of Bazou town. This locality administratively belongs to the Division of Nde in the Western Region of Cameroon. The clay deposit is in Tsila village. Balengou's boundaries are Bamena to the North, Nkam to the South, Batchingo to the West and Bazou to the East. Geographically, it lies between longitudes 5 ° 06'28 "North and latitudes 10 ° 26'10" East and is presented in figure 3.1.

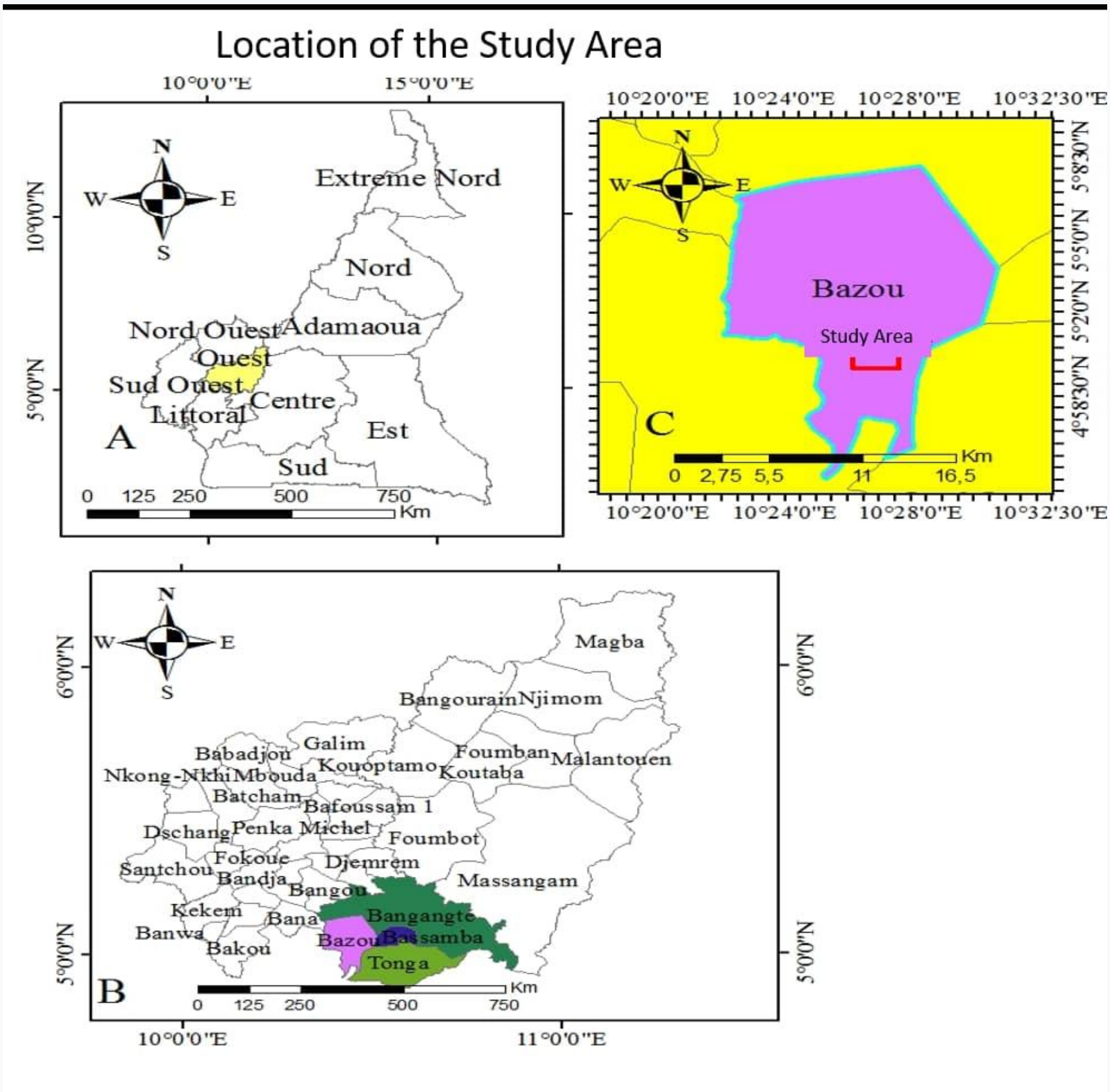

Figure 3.1: Location of the study area

The choice of the site is based on surveys and the work of Wandji F. L. which revealed the ancient and current non industrial use of these materials for trading. Field trips and surveys carried out on this site have provided insight into the economic activity that emerges from this deposit. The materials of this site, because of their important use, will be analyzed for possible use in concrete.

This quarry is exploited by women. They dig wells at varying depths to locate the level of material being mined and estimate the volume of material on the hill. These samples are then taken in polyethylene bags for laboratory analysis. The kaolin sampling is preceded by the morphostructural description of the wells and outcrops of the locality.

The Balengou clay deposit is a shallow formation with light brown, pink-reddish colour. Halloysite clay occurs as coiled crystals, forming tubes. It contains additional water called zeolite water, due to its high refractory properties (melting point 1730 ° C-1785 ° C). Halloysite is different from kaolinite in the water it contains between the layers.

Halloysite clays undergo significant and irreversible transformations at each temperature range during firing, to ultimately give completely different materials from the point of view of physical, chemical, mechanical, thermodynamic or structural characteristics. Activation of clay materials is a process of changing the crystal structure in order to make the material more reactive to its environment. Balengou halloysite clay is presented in figure 3.2.

Figure 3.2: Halloysite clay from Balengou

3.2. Materials

The raw materials used in our study are halloysite clay, sand (0/5), gravel (5/15), gravel (15/25), water and DANGOTE CEM II cement 42.5R.

- The cement used in this study is DANGOTE CEM II 42.5R type cement of true class σ'c = 42.5 MPa, EN 196-1.
- The sand 0/5 used for making concrete is River Sanaga sand, which complies with the requirements of standard EN 196-1 and of standard ISO 679: 2009.
- The gravel is the 5/15 and 15/25 crushed one from the RAZEL quarry in **Nkometou** near Yaoundé.
- The halloysite clay comes from Balengou located in the Nde division, Western Region of Cameroon. The NF P18-513 standard on the use of metakaolin, as a pozzolanic addition for concrete, explains and justifies the various criteria used for its development. The different chemical and physical requirements are presented:

• Chemicals: the content of silica, alumina, chloride, sulfate, free calcium oxide, magnesium oxide, as well as the loss on ignition, the blue value and the fixation of calcium hydroxide,

• Physical: fineness, activity index, water demand.

3.3. Materials

- A GPS
- A Munsell code;
- A pickaxe, a hoe; a dibble; a trident and a decameter.
- A wheelbarrow;
- A round shovel;
- Extraction: machete, hoe, buckets and bags;
- Calcination: the adjustable oven temperature;
- The manufacture of concrete: the shovel, the trowel, the scale, the cylindrical molds, the concrete mixer;
- The drum of water;
- Calcination of clay: oven;
- Sieve analysis: Square mesh sieves;
- Cleaning the sieves: the wire brush;
- Molding of test specimens: cylindrical molds 16 x 32, trowel, round shovel;
- Slump test measure: Abrams cone;

- Crushing of the test pieces: the press;
- The balance;
- Preparation of end surfaces of specimens: sulfur;
- Density: graduated cylinder and pycnometer;
- Sand equivalent: test tube, 5l bottle funnel, measuring ruler, calibrated piston, washing solution
- Crushing the clay: the drum.

3.4. Field method

The methods of surveys, choice of the site, opening of the wells, extraction of the kaolin, morphostructural description, and supply of aggregates constitute the methods carried out in the field.

Surveys in the market made it possible to identify traders, locate the quarry and clay materials exploited for selling, consumption by pregnant women in Balengou and its surroundings. According to clay therapists interviewed in the markets of the locality, Balengou kaolin has therapeutic properties, and were also used for body care, rheumatism and fractures.

3.5. Laboratory method

3.5.1. Physical and thermal treatments of clay

The natural clay is first dried at room temperature and then ground for a long time in a G91 type ball mill. It is important to grind the material well and to sieve at 2µm (Day et al., 1994; Shi., 2001). This clay will then be placed in the oven to undergo the heat treatment.

The heat treatment consisted of placing the clay in an electric furnace which was raised to a temperature of 750 ° C to create excitement within the material. It is this excitemen that makes the material more reactive hence it becomes pozzolanic (Bich et al., 2009; Elimbi et al., 2011; Rashad, 2013). The thermal activation of halloysite clays has been widely studied for use in cementitious materials. Several studies can be found in the literature that have studied the thermal activation temperature of clays as well as the activation time.

3.5.2. Particle size analysis test of aggregates

This test is carried out according to the prescriptions of standard NF EN 933-1 (2012). The coefficient of uniformity, the coefficient of curvature and the fineness modulus were determined.

3.5.2.1. Hazen coefficient or coefficient of uniformity (C_u) and coefficient of curvature (C_z)

The particle size distribution was determined by the method of dry sieving, according to the French Standard NF EN 933-1(2012).

After performing the particle size analysis, the coefficients of uniformity (C_u) and curvature (C_z) are determined respectively by expressions 1 and 2:

$$\mathbf{C_U = \frac{D_{60}}{D_{10}}} \quad \textbf{(1)}$$

$$\mathbf{C_Z = \frac{(D_{30})^2}{D_{60} \times D_{10}}} \quad \textbf{(2)}$$

Where D_{60}, D_{30} and D_{10} are respectively the particle dimensions corresponding respectively to 60%, 30% and 10% passing on the cumulative particle size distribution curve.

3.5.2.2. Fineness modulus

After performing the particle size analysis, the fineness modulus (FM) is determined as equal to one hundredth of the sum of the cumulative percentages of mass retained on the following sieve sizes: 0.16, 0.315, 0.63, 1.25, 2.5, 5.0 mm according to the prescriptions of the French Standard NF P 18-540 (1997). It is therefore determined using the expression 3:

FM = (1/100) ∑ Cumulative percentages of mass retained on sieves {0.16-0.315-0.63-1.25-2.5-5} (3)

3.5.3. Water content test

The water content w (%) is determined in accordance with the French Standard NF P 94 - 049 - 1 (1996), the results are expressed by relation 4.

$$\boldsymbol{w}(\%) = \mathbf{100}\, \frac{M_h - M_s}{M_s} \quad \textbf{(4)}$$

Where M_s is the mass of the dry sample after drying in an oven at 105 ° C for 24 hours, M_h is the mass of the sample as collected from the site.

3.5.4. Sand equivalent test

This test is carried out using graduated plastic cylinder previously filled partially with washing solution according to the French Standard N F EN 933-8 Part 8 (1999) to measure the cleanliness of the materials studied with dimension less than or equal to 5 mm. The sand equivalent (SE) is the average of the values of the sand equivalent visually (SE_V) and that at the piston (SE_P). The values are determined respectively by the following expressions 5, 6 and 7:

- $$SE = \frac{SE_V + SE_P}{2} \quad (5)$$
- $$SE_V = \frac{H_2}{H_1} \, x \, 100 \quad (6)$$
- $$SE_P = \frac{H'_2}{H_1} \, x \, 100 \quad (7)$$

Where H_2 and H'_2 are respectively the heights of clean sand measured visually and with the piston, and H_1 the total height of clean sand and fine elements.

3.5.5. Density tests

It is the mass per unit of volume of a body. There are specific gravity and bulk density.

3.5.5.1. Specific gravity test

The specific gravity is the mass per unit volume of the material excluding all voids between aggregates.

The test consists of measuring the proper volume of the grains excluding voids and calculating the ratio between their weight and their volume by the method of pycnometer as described in French standards NF P 94-054 (1991) and NF P 18-555 (1990). The specific gravity (ρ_s) is determined by expression 8:

$$\rho_S = \frac{M}{M_1 + M - M_2} \rho_W - \alpha_t \quad (8)$$

Where M is the mass of material compatible with the dimensions of the pycnometer in kg, M_1 is the mass of the pycnometer filled with distilled water up to the benchmark line in kg, M_2 expressed in kg, is the total mass of the pycnometer, water and sample, α_t represents a correction factor depending on the temperature of the experiment as defined in Table 3.1

Table 3.1: Correction Coefficient α_t fonction of the temperature of experience

T° of water (°C)	18	19	20	21	22	23	24	25
α_t	0,004	0,004	0,005	0,006	0,006	0,007	0,008	0,008

3.5.5.1. Bulk density test

The bulk density of an aggregate (ρ_a), described by the French standard NF X31-503 (1992), is the ratio of the mass of the wet aggregate to the apparent volume (V) and is expressed by the expression 9:

$$\rho_a = \frac{M_2 - M_1}{V} \quad (9)$$

Where ρ_a is the bulk density in g / cm3, M_1 is the mass of the empty container in g, M_2 is the mass of the full, flattened container in g, V is the net volume of the container measured in cm3.

3.5.6. Design mix of reference concrete type C25 / 30

Dupain and Saint-Arroman (2009) method and the Dreux-Gorisse (1983) method are used. The composition of the concrete is determined with a compressive strength targeted at 28 days σ'_{28} is 28.75 MPa, the minimum compressive strength necessary for the stability of the structure is f_{c28} = 25 MPa. The value of the concrete characteristic strength is greater than the minimum value by 15% for safety reasons and a slump of 70 mm for plastic consistency. The vibration is normal, the granular coefficient G is 0.5 because current and good aggregates, with maximum dimension Dmax of 25 mm. The dosage of cement C is equal to 350 kg / m3.

3.5.7. Design mix of metakaolin concretes

The design mix of the concretes was done with Dreux-Gorisse method with a characteristic compressive strength at 28 days of 25 MPa and a slump of 70 mm for plastic consistency. The dosage of cement like binders L (C + MK) is 350 kg / m3. The cement likes binders used are obtained by partial substitution of the cement by different percentages of metakaolin (0, 10, 20, 30 and 40%) with the same consistency for a slump of 70 mm with all the concrete compositions, the L / E ratio is held constant L / E is 1.853 where E is the mass of water in the mix.

3.5.7.1. Design mix for the manufacture of metakaolin concrete specimens

The strengths are measured on cylindrical test specimens, which have the dimensions 16 cm x 32 cm (16 cm in diameter and 32 cm in height). Six (06) specimens per type of metakaolin concrete representing a volume of 0.03858432 m3 are made and crushed, including three (3) at 7 days and three (3) at 28 days, for a total of thirty (30) specimens. A rule of proportionality is used to determine the masses of different constituents of MKC knowing the masses for one (1) m3.

3.5.7.2. Compression test on concrete specimens

The test specimens are immersed in water immediately after demoulding after 24 hours and during their life of 28 days.

- Compression test on metakaolin concrete (standard NF P 18-400, EN 12390-1, EN 12390-2 and EN 12390-3);
- Preparation of end surfaces of specimens (EN 12390-3 standard;
- The maximum recorded load (F) during the test for rupture of specimens. It is determined by relation 10:

$$f_{Cd} = \frac{F}{S} \qquad \textbf{(10)}$$

Where F is Maximum recorded load (F) during the test for rupture of specimens in meganewtons (MN), S is the Cross sectional area of the specimen in m2, fcd compressive strength in MPa.

From a calculation, the tensile strength on d day (f_{td}) is given by relation 11:

$$f_{td} = 0,06 f_{cd} + 0,6 \qquad \textbf{(11)}$$

Where f_{td} et f_{cd} are in MPa

IV. Results And Discussion

The results of the surveys, the presentation of quarries, the calcination of kaolin, the particle size analysis, the slump test, the density test, the concrete design of mix and compression test are presented in this chapter.

4.1. In the field

Observations made in the field gave an idea of the location of the quarries and the various clay materials identified in the study area. Surveys carried out at the Balengou market identified six halloysite clay women traders. Surveys carried out among the populations revealed that Tsila village is the main site of extraction of clay materials of the study area. The extraction of clay is a predominantly female activity. Investigations also reveal that the materials are used locally by populations for consumption and treatment of gastric ulcer. This clay is heavily consumed by pregnant women. The quarry is the place of extraction of the clay raw material. The Balengou quarry is located in Tsila village.

Considering that this hill where the clay is extracted is assimilated to a cone, the height can be obtained from the difference in altitude taken at the base (1502 m) and at the summit (1596 m), approximately 100 m, the radius of the base is estimated as 137 m, that is a quarry with about two million (2,000,000) m^3 of clay.

The clays from this site are the most widely used for trading and treatment of diseases. A well is dug at the lower end of the quarry embankment slope. Colluvial materials are found at the lower end of the slope, which are mixtures of laterites from the hill and alluvium from the bottom. The well dug directly at the lower end of the embankment enables the materials collected to reach a yellowish-brown level, slightly rich in rock fragments.

4.2. In the laboratory

4.2.1 Product obtained after physical and thermal treatments

The product obtained after physical and thermal treatments is presented in figure 4.1.

Figure 4.1: Clay after physical and thermal treatments

Figure 4.1 shows the powder of metakaolin, obtained by sieving after physical and thermal treatments whose dimensions are less than 2 µm.

4.2.2. Particle size composition of the aggregates used

The particle size analysis is performed on an electric vibrating agitator on which the sieves from bigger to smaller are embedded from top to bottom. The passing on each sieve is weighed and the percentages calculated. The results of particle size analysis are presented in Table 4.1 and Figure 4.2.

Table 4.1: Particle size composition of the sand and gravel used

Materials studied	Sanaga Sand 0/5	Gravel 5/15 from Razel Nkometou quarry near Yaounde	Gravel 15/25 from Razel Nkometou quarry near Yaounde
Dimensions of sieve (mm)	Percentage passing (%)		
31,5	-	-	100
25	-	-	95
20	-	100	23
16	-	93,2	12
12,5	-	59,4	1
10	-	29,4	-
8	-	15	-
6,30	-	4,1	-
5,00	100	0,7	-
3,15	98	-	-
2,5	94	-	-
0,63	29	-	-
0,315	8	-	-
0,080	0	-	-

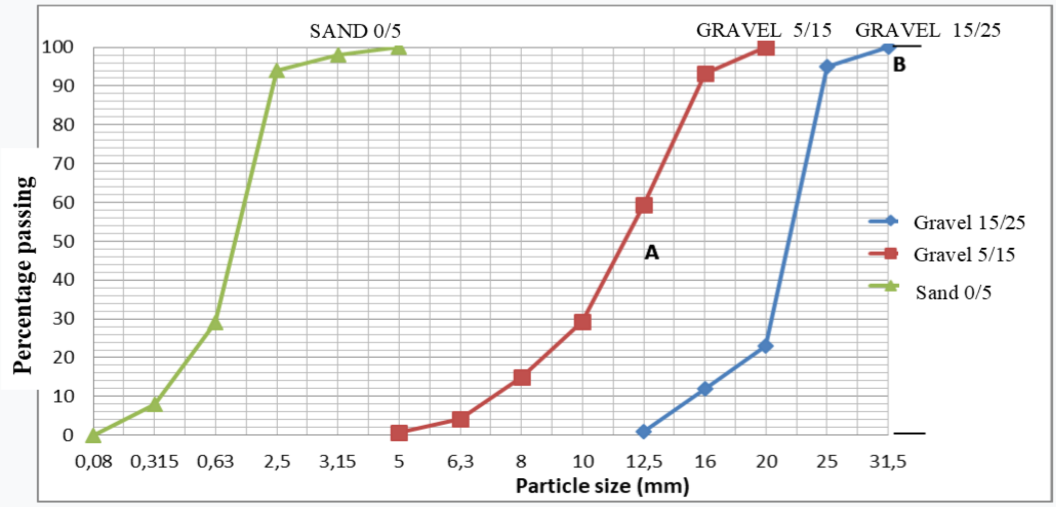

Figure 4.2: Particle size distribution curves of aggregates

Following the result of the particle size analysis in Table 4.1 and Figure 4.2, the **Coefficient of uniformity**, the **coefficient of curvature and the fineness modulus** are presented in Table 4.2.

Table 4.2: Coefficient of uniformity, Coefficient of curvature and fineness modulus

Materials studied	Coefficient of uniformity Cu	Coefficient of curvature Cz	Fineness modulus
Sanaga Sand 0/5	4,42	0,8	3,09
Gravel 5/15 from Razel Nkometou quarry near Yaounde	1,75	1,1	-
Gravel 15/25 from Razel Nkometou quarry near Yaounde	1,46	1,2	-

From table 4.1, table 4.2, and figure 4.2, the value of the fineness modulus is equal to 3.09 and according to the French Standard NF P 18-541 (1994), the aggregates are very coarse and can increase the strength while not facilitating the workability of the concrete. They may also be used after correction by adding finer sand to reduce the fineness modulus between 2.2 and 2.8 and increase the workability. The fineness modulus of the sand used is similar to that determined by Moundom et al. (2016) for the black pozzolana sands of Ngouogouo with value of 4.21 and for the brown pozzolana sands of Mfosset with value of 4.07 but different from the fineness modulus of 2.09 determined by the same author for the sands of black volcanic ash of Baïgom which are fine sands.

The value of the coefficient of curvature is not between 1 and 3 for sand and that of the coefficient of uniformity is not greater than 6 for the same sand and this shows that the aggregates are poorly graded (Robitaille and Tremblay, 1997). The value of the coefficient of curvature is not between 1 and 3 for 5/15 gravel and 15/25 gravel and that of the coefficient of uniformity is not greater than 4 and this shows that the aggregates are poorly graded (Robitaille and Tremblay, 1997).

4.2.3. Water content
After drying all the aggregates used for the tests in an oven at 105 ° C for 24 hours, the water content (ω) is zero.

4.2.4. Bulk density and specific gravity of the components of metakaolin concrete
The bulk density and specific gravity of the components of metakaolin concrete are presented in Table 4.3.

Table 4.3: Bulk density and specific gravity of the components of metakaolin concrete

Materials studied	Bulk density (t/m^3)	Specific gravity (t/m^3)
Gravel 15/25 from Razel Nkometou quarry near Yaounde	1,494	2,812
Gravel 5/15 from Razel Nkometou quarry near Yaounde	1,536	2,806
Sanaga Sand 0/5	1,467	2,637
DANGOTE Cement 42.5R	1,1	3,1
Metakaolin from Balengou	0,717	2,1
Water	1,03	1,03

According to Table 4.3, the densities of aggregates are between 2 t / m3 and 3 t / m3. In accordance with French Standards EN 12620 (2008), NF P 18-554 (1990) and NF P 18-555 (1990), aggregates are said to be current ones. In addition, metakaolin powder is less heavy than cement.

4.2.5. Sand equivalent value
The sand equivalent value of the sand used is presented in Table 4.4.

Table 4.4: Sand equivalent value of the sand used

Materials used	Sand equivalent value		
	Visual value	From piston	Average
Sanaga Sand 0/5	98,5	96,7	97,6

From table 4.4, the sand used of dimension less than or equal to 5 mm has the value 97.6% for Sand Equivalent value which is greater than 80% indicating that this sand is very clean according to the French Standard NF EN 933- 8 Part 8 and the almost total absence of fine dust or clay-like materials may cause lack of plasticity in the concrete, which must be corrected by increasing the quantity of cement in the mix (Dupain and Saint-Arroman, 2009). The sand equivalent value is similar to those determined by Moundom et al. (2016) for the black pozzolana sands from Ngouogouo with value of 96.1% and to those of the brown pozzolana sands from Mfosset with value of 95.8% but different from 78.9% determined by the same author on the black volcanic ash sands from Baïgom which are clean with low percentage fine dust of clay-like materials which are very suited for quality concrete (Dupain and Saint-Arroman, 2009).

4.2.6. Composition of the reference concrete C25 / 30

The characteristics of the reference concrete are presented in table 4.5 and the granular skeleton determined from Dreux-Gorisse.

Table 4.5: Characteristics of the reference concrete C25 / 30

Constituents of the C25/30 Concrete	Mix Quantities
Gravel 15/25 from Razel Nkometou quarry near Yaounde	795,23
Gravel 5/15 from Razel Nkometou quarry near Yaounde	416,61
Sanaga Sand 0/5	727,10
Dangote Cement CEM II 42,5 R	350,00
Water	188,89
Total	2477,83

According to Dreux-Gorisse, the percentages of the absolute volumes of aggregates are 39 for 0/5 sand, 21 for 5/15 gravel and 40 for 15/25 gravel. These percentages of the absolute volumes gave 350 kg / m3 of Dangoté CEM II 42.5 R cement, 188.89 liters of water, 727.10 kg of sand, 416.61 kg of gravel 5 / 15 and 795.23 kg of gravel 15/25. These different quantities gave a theoretical concrete density of 2478 kg / m3.

4.2.7. Dosages of metakaolin concretes (MKC)

The composition of the concretes was determined by Dreux Gorisse method with the characteristic compressive strength at 28 days of 25 MPa and a slump of 70 mm for plastic consistency. The dosage of cement like binders L or (C + MK) is 350 kg / m3. The cement like binders used are obtained by partial substitution of the mass of cement by different percentage masses of metakaolin (0, 10, 20, 30 and 40%) with the same consistency for a slump of 70 mm for all compositions used, the L / E ratio is held constant at L / E = 1.853 where E is the mass of water. The dosage of metakaolin concretes per cubic meter is presented in Table 4.6.

Table 4.6 : Metakaolin Concrete mix per cubic metre

Composition	Sand 0/5 (kg)	Gravel 5/15 (kg)	Gravel 15/25 (kg)	Dangote Cement 42.5R (kg)	Metakaolin (kg)	Water adjustment for initial slump	Total Water (l)
MKC_0	727,10	416,61	795,23	350	0	0	188,89
$MKC_{10\%}$	727,10	416,61	795,23	315	35	26,98	215,87
$MKC_{20\%}$	727,10	416,61	795,23	280	70	53,96	242,85
$MKC_{30\%}$	727,10	416,61	795,23	245	105	80,95	269,84
$MKC_{40\%}$	727,10	416,61	795,23	210	140	107,93	296,82

From Table 4.6, the combination of cement and metakaolin remains constant at 350 kg but the quantity of water increases in the mixture. This situation is explained by the water absorbed by the metakaolin powder to obtain the consistency of the reference concrete.
The dosage for manufacturing six test pieces of each composition (0.0386 m3) is presented in Table 4.7.

Table 4.7: Metakaolin Concrete mix for six cylindrical specimens per composition

Composition	Sand 0/5 (kg)	Gravel 5/15 (kg)	Gravel 15/25 (kg)	Dangote Cement 42.5R (kg)	Metakaolin (kg)	Water (l)	Number of specimens
MKC_0	28,068	16,082	30,7	13,5	0	7,2	6
$MKC_{10\%}$	28,068	16,082	30,7	12,16	1,35	8,33	6
$MKC_{20\%}$	28,068	16,082	30,7	10,808	2,702	9,37	6
$MKC_{30\%}$	28,068	16,082	30,7	9,458	4,053	10,41	6
$MKC_{40\%}$	28,068	16,082	30,7	8,106	5,404	11,46	6

4.2.8. Densities of metakaolin concrete

The densities of metakaolin concrete are presented in table 4.8.

Table 4.8: Densities of metakaolin concrete (MKC)

Concretes	Density after demolding (kg/m^3)	Density before compression (kg/m^3)
MKC_0	2470,36	2472,25
$MKC_{10\%}$	2496,28	2503,60
$MKC_{20\%}$	2522,20	2534,71
$MKC_{30\%}$	2548,11	2550,26
$MKC_{40\%}$	2574,45	2581,36

Table 4.8 shows that the densities of metakaolin concretes are almost identical to the theoretical density of the designed reference concrete showing that there is no need to readjust the different design mixes. According to standard NF EN 206 / CN (2014), concrete is qualified as normal since the densities are between 2000 and 2600 kg / m3,

4.2.9. Compressive and tensile strengths **of metakaolin concretes at 7 and 28 days**

The **compressive** and tensile strengths of metakaolin concretes at 7 days are presented in Table 4.9 and those at 28 days presented in Table 4.10 and the recapitulation presented in Figure 4.3.

Table 4.9: Compressive and tensile strengths **of the composition at 7 days**

Composition	Concrete specimen	Forces (kN)	Specimen mass (kg)	Specimen compressive strength f_i (MPa)	Compressive strength f_{cd} (MPa)	Tensile strength f_{td} (MPa)
MKC$_{0\%}$	A	344	16,145	17,20	**18,40**	**1,70**
	B	384	16,340	19,20		
	C	376	16,330	18,80		
MKC$_{10\%}$	A	424	17,128	21,20	**20,73**	**1,84**
	B	404	17,320	20,20		
	C	416	17,215	20,80		
MKC$_{20\%}$	A	452	17,258	22,60	**21,20**	**1,87**
	B	400	17,325	20,00		
	C	420	17,428	21,00		
MKC$_{30\%}$	A	356	16,254	17,80	**18,60**	**1,72**
	B	368	16,427	18,40		
	C	392	16,326	19,60		
MKC$_{40\%}$	A	372	16,542	18,60	**18,80**	**1,73**
	B	376	16,364	18,80		
	C	380	16,124	19,00		

According to Table 4.9, the compressive and tensile strengths of concrete at 7 days with a non-zero percentage of metakaolin are greater than those for the reference concrete designed and manufactured.

Table 4.10: Compressive and tensile strengths **of the composition at 28 days**

Composition	Concrete specimen	Forces (kN)	Specimen mass (kg)	Specimen compressive strength f_i (MPa)	Compressive strength f_{cd} (MPa)	Tensile strength f_{td} (MPa)
MKC$_{0\%}$	A	500	16,455	25	**26,17**	**2,17**
	B	540	16,330	27		
	C	530	16,070	26,5		
MKC$_{10\%}$	A	545	16,405	27,25	**27,21**	**2,23**
	B	547	16,280	27,35		
	C	540	16,020	27		
MKC$_{20\%}$	A	607	16,888	30,35	**30,12**	**2,41**
	B	660	16,763	33		
	C	540	16,503	27		
MKC$_{30\%}$	A	624	15,996	31,2	**30,5**	**2,43**
	B	586	16,121	29,3		
	C	620	15,736	31		
MKC$_{40\%}$	A	596	15,636	29,8	**30,65**	**2,44**
	B	631	16,021	31,55		
	C	612	15,896	30,6		

According to Table 4.10, the compressive and tensile strengths of concrete at 28 days with a non-zero percentage of metakaolin are greater than those for the reference concrete designed and manufactured.

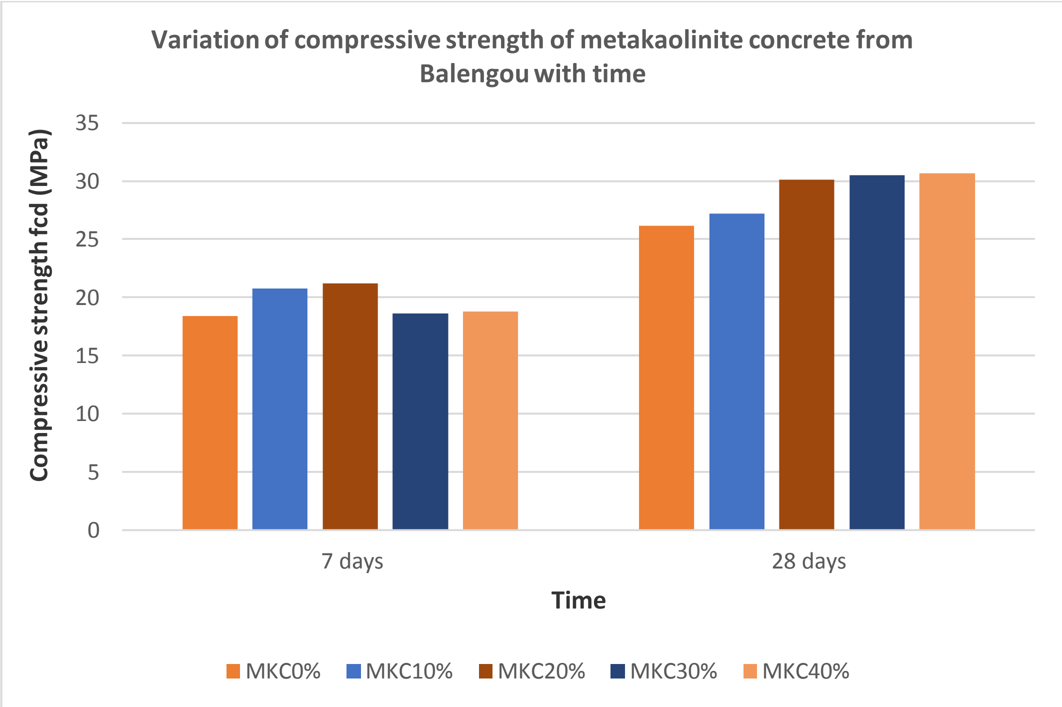

Figure 4.3: Compressive strengths **of metakaolin concretes 7 to 28 days**

According to Figure 4.3, the compressive strengths of concrete at 7 days with non-zero percentage of metakaolin are greater than those for the reference concrete designed and manufactured. This increase has the maximum values of 21.20 MPa for compression and 1.87 MPa for traction for $MKC_{20\%}$ corresponding to the replacement of the cement in the concrete by 20% of metakaolin. The compressive strengths of concrete at 28 days with a non-zero percentage of metakaolin are greater than those for the reference concrete designed and manufactured. This increase has the maximum values of 30.65 MPa for compression and 2.44 MPa for traction for $MKC_{40\%}$ corresponding to the replacement of the cement in the concrete by 40% of metakaolin. The 28-day compressive strength value of 30.65 MPa is greater than the characteristic compressive strength of 25 MPa at the same date considered during the design of mix. According to French Standard NF EN 206 / CN (2014), these concretes fall into the category of normal concretes.

The compressive strength values here are higher than those determined by Moundom et al. (2018) on Foumbot's lightweight pozzolana concretes with values between 3.87 and 8.26 MPa, higher than those determined by Mbessa et al. (2012) on concretes with partial replacement of the cement by Djoungo pozzolanas with values between 12.13 and 0.96 MPa.

V. Conclusions And Recommendations

The objective of the present work is the study of the mechanical properties of metakaolin concrete (MKC) based on the partial substitution of cement in a reference concrete with Balengou halloysite clay in West Cameroon. The clay heat treatment test, the particle size analysis test of the aggregates used, the water content test, the sand equivalent test, the specific gravity and bulk density test, the mix design of the reference concrete by the Dreux - Gorisse method, the mix design of metakaolin concrete with partial substitution of the cement in the reference concrete by 0, 10, 20, 30 and 40% of halloysite clay from Balengou namely $MKC_{0\%}$ $MKC_{10\%}$ $MKC_{20\%}$ $MKC_{30\%}$ and $MKC_{40\%}$. The results obtained were impressive with 21.20 MPa and 1.87 MPa at 7 days for $MKC_{20\%}$ in compression and tension respectively, 30.65 MPa and 2.44 MPa at 28 days for $MKC_{40\ \%}$ in compression and tension respectively. The finding here showed that the mechanical strengths are greater than the characteristic values 25 MPa and 2.1 MPa in compression and in tension at 28 days targeted during the design of mix.

This work could not go beyond 28 days to further appreciate the strengths of metakaolin concrete. As a perspective, the study could extend beyond 30 and 60 days in order to better validate the Balengou's holloysite clay in the production of cement and concrete.

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