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MINERALOGICAL AND PHYSICAL CHARACTERIZATION OF LOUM POZZOLAN IN THE CAMEROON VOLCANIC LINE, SOUTH-WEST REGION, CAMEROON: IMPLICATIONS IN CEMENT MANUFACTURING

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Abstract

Supplementary cementitious materials are currently one of the most recent developments in cement production, as they are used to reduce the consumption of Portland clinker, contributing in solving the environmental (CO_2 production) and economic problems. This experimental work studies the advantages and the possibility of partial substitution of Portland clinker by Loum natural pozzolan in cement. Practically, the study aims at testing the quality of cement at its various degrees of the above material substitution which can be 0%, 10%, 20%, 30%, and 40%. This will help to better determine the characteristics of the Loum natural pozzolan based cement and the mechanical behaviour of the resulting paste and mortar. The features of the raw materials used in this study (mineralogical composition by XRD, grinding time, specific weight and density, consistence of cement pastes and setting time), as well as the characteristics of mortars prepared by these cements such as absorption, removal, mechanical behaviour (flexural and compressive strengths) for the mortar were studied. From the experimental results obtained, it comes out that the quantity of mineral additive Loum pozzolan and the chemical composition of cement manufactured are the principal parameters which influence the variation of the mechanical strengths (flexural and compressive) of the mortars tested.

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Keywords: Cameroon Volcanic Line, Pozzolan, Loum, Cement

1. Introduction

Developing countries generally need cement, concrete and mortar for the development of their infrastructures. However, the increase in the market prize of Portland cement (CEM I) today and that of its main constituent (clinker), may greatly limits this development. Generally these countries rely on imported cement to develop new infrastructure for their projects. Even some of these developing countries that produce cement still face difficulties to satisfy the needs of the market, increasing the need of imported cements and/or some of its components either to close the gap or to meet their quality standards. Despite all these efforts, the cost of cement is still out of reach for the majority of the population, making it difficult to achieve the objective of economic and infrastructure development. It is in an attempt to curb the cost of cement while maintaining the quality that many studies have been carried out to assess the role that pozzolan can play by replacing at least a percentage of clinker in above CEM I in order to produce Pozzolanic cement in compliance with standards (EN 197–1 2011; ASTM C-618 2015; NC 234:2017 2017, Bondar et al., 2011; Firdous et al., 2018). Many authors investigated on the characteristics required for a material to be call Pozzolans (Mbowou et al., 2020; 2022; Leroy et al., 2019). A pozzolan is defined in the ASTM C125 standard as "a siliceous and aluminous material which contains: constituents having little or no cementitious properties in their own right, but which, in fine, divided form and in the presence of moisture, react with calcium hydroxides at ordinary temperatures to form relatively stable, water-insoluble compounds with cementitious compounds". Since Roman times, pozzolans have been widely used for construction purposes, acquiring their name from the present-day village of Pozzuoli, Naples, Italy (OULD MOUSSA et al., 2000).

During the manufacturing process of cement, the raw materials generate chemical reactions that produce CO_2. The substitution of Portland cement clinker by a natural or artificial pozzolan for is one of the successive processes developed to reduce CO_2 emissions in the cement industry. Cement production is a source of pollution and ozone depletion due to its anthropogenic carbon dioxide emissions. It is therefore urgent that new materials, especially local ones, are developed that can combine good strength with very low carbon dioxide emissions. Being a country of volcanic origin, Cameroon Volcanic Line (CVL) with its active volcano therefore contains numerous centres of volcanic emissions. The CVL trends SW–NE and shows alignment of volcanic massifs on about 1600 km from Pagalu in the Gulf of Guinea to Chad Lake (Fig. 1a, Deruelle et al., 2007) and extruded by plutons of tertiary to actual volcanism. This structure displays oceanic and continental sector made-up mostly of

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large polygenic volcanoes and grabens. The continental sector is sub-divided in to the Bamileke Plateau, the Noun Plains and the Tombel plain. This latter represents the area under study. It displays altitudes that vary between 150–300 m (Wandji and Tchoua, 1988; Sah and Tchindjang, 2021). It is characterized by several low slope monogenic volcanic cones from recent (0.6–0.05 Ma) explosive volcanisms disseminated in this zone and where some of the Pozzolanic production is actually taking place (Lee et al., 1994; Wotchoko et al., 2005; Nkouathio et al., 2008; Juimo et al., 2017b). Specifically, in the coastal region, Mount Manengouba (2411m, 4°58'44'' N 9°50'31'' E) is a hot spot volcano though extinct. Its last eruption remains unknown. The local production of pozzolan takes place in Loum, a small city on the Douala-Bafoussam high way. The demand for cement is constantly increasing in Cameroon, confirms the Minister of Trade. He recorded an increase of 14% between 2020 and 2025; a year in which cement use is expected to around 8 million tons.

Research has been carried out to find low-cost binders that can replace Portland cements, especially for the most commonly used types: CPA 45 and CPJ35, as the high price of cement worldwide is due to the high cost of manufacturing clinker. Indeed, the idea is to work on natural pozzolans, which are products that react at room temperature with lime and water to give rise to binding properties (Mbowou et al., 2022). Natural pozzolans are still useful as a replacement for blast furnace slag from large plants, a constituent conventionally used in the manufacture of cement.

Nevertheless, the interest in using pozzolans as hydraulic binders is based on the principle of strengthening the resistance to attack; this would make it possible to obtain mortars and concretes with the same properties. However, Cameroon as volcanic countries already have pozzolanic deposits that must be exploited for some, and already exploited for others for a better technological interest to our income.

This experimental study assesses the effect of Portland clinker substitution by natural Loum pozzolan at different percentages (0%, 10%, 20%, 30% and 40%) on the mineralogical and physic-chemical characteristics of the prepared cements and mortar mechanics at their bases. It also examines the protection of the environment by reducing the use of Portland cement and production of CO_2 which will be replaced by using an optimal percentage of natural pozzolan. To this end, a study on the characterization from mineralogy, chemistry and physics of natural pozzolan acquired in the deposit of the Loum area and the evaluation of their reactivity as pozzolanic additive in the lime paste for cement manufacture will be examined. The detection and progression of the reaction products are monitored by X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR). Therefore, mixing natural pozzolan, which is one of the most promising uses of natural zeolites due to its characteristics and economic advantages, will lead us to study the analysis of the flexural

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and compressive strength after 7 and 28 days of the mixtures obtained. The morphological, mineralogical and microstructural properties of the hydrated products will also be examined on mortars after 7 and 28 days of hydration.

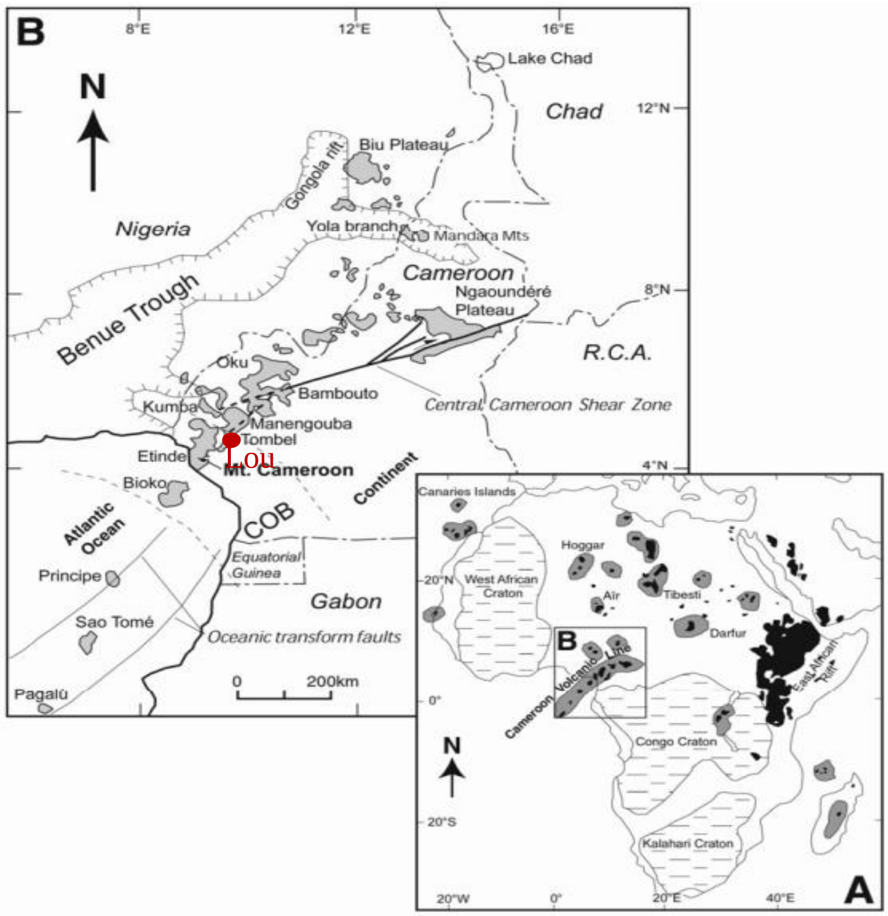

Fig. 1: A) Location map of the Cameroon Volcanic Line (CVL). The main geological features of Africa are indicated: eastern African volcanism linked to rifting (black) and intra-plate (continental or oceanic) volcanic provinces (grey). B) Location of Mount Cameroon and other main volcanic centres (grey) along the Cameroon Volcanic Line. Dashed lines are boundaries between the CVL segments: Atlantic Ocean, Continental Ocean Boundary (COB) and continent (Modified after Wandji et al., 2009 and after Nkouathio et al., 2008).

2. Methodology

2.1. Field work and sampling

Two field work campaigns with a total of five days (first campaign, three days and second campaign, two days) were carried out in the study area and a total number of 23 representative samples was collected in the Loum pyroclastic cone in accordance to their accessibility and actual uses for industrial or artisanal purposes. The Loum cone (Fig. 2)

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displays a large variety of pozzolan type characterized by their respective coulor and the size of particle and grains (Fig. 2A, 2B, 2C)).

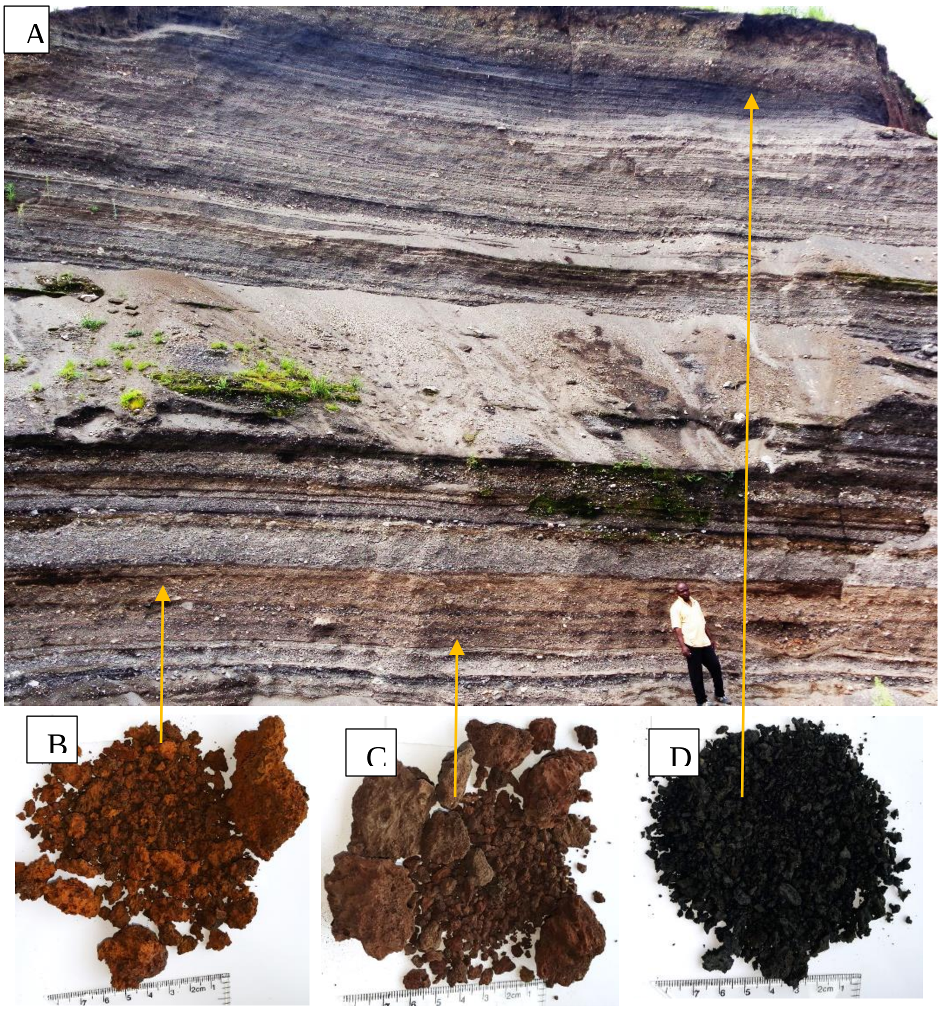

Figure 2: A) Cone of pozzolans in Loum, showing a wide variety of occurrence and colour, B) Red pozzolan, C) Brown Pozzolan D) Black pozzolan

2.2. Mixture formulation and preparation of specimens

The mixtures and the preparation of specimens were carried out in accordance with the standards in force at the Civil Engineering Laboratory of ENSET of Douala: after the preparation of the various components following crushing and sieving, these materials were mixed, according to well defined proportions, in order to obtain more or less homogeneous products.

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In this study, clinker is substituted at different percentages by natural pozzolan (0%, 10%, 20%, 30% and 40%), in order to study the effect of this pozzolanic addition on the evolution of the properties of a cement matrix. To have an in-depth idea on this influence, the study will be based on cement pastes as well as standardized mortars. The ratio cement/sand and water/cement that allows a good workability of mortars and cement pastes were respectively 0.33 and 0.5 for mortars and 0.305 for pastes.

After homogenization, the fresh mortars were placed in standardized moulds to make prismatic specimens of section 4 cm × 4 cm and length 16 cm; the pastes were tested for initial and final setting time. The moulds were then vibrated to eliminate air bubbles and kept for 24 hours for consolidation at an ambient temperature of 24 ± 2°C. Demoulding was performed 24 h after moulding, and labelled for later identification before immersion in water for curing.

After demoulding, immerse without delay the marked specimens, either horizontally or vertically, in water and in suitable containers. When specimens are stored horizontally, the compression faces that were vertical at the time of moulding should remain vertical and the flush surface should be placed upward. Specimens were placed on non-corroding racks and separated from each other so that water can freely access all six sides of the specimens. At no time during the storage should the water gap between specimens be less than 5 mm. Only specimens made of cement of comparable chemical composition may be stored in the same container. Use city water for initial filling of containers and for occasional additions to maintain a reasonably constant water level. During storage of the test tubes, it is not permitted to change the water completely. Test specimens, which are to be tested at particular times (other than 24 h or 48 h in the case of delayed demoulding), must be removed from the water not more than 15 min before the test is carried out. Remove any deposits from the test faces. Cover the test specimens with a damp cloth until the time of testing.

2.3. Mineralogical analyses of samples by X-ray diffraction (XRD)

X-ray diffraction (XRD) is an analytical technique based on the interaction between X-rays and matter. When the wavelength λ of incident radiation (X-rays) is of the same order of magnitude as the inter-reticular distances (d) of a crystal or powder, there is radiation-matter interaction according to Bragg's equation (1):

$$2d \sin\theta = n\lambda \quad \text{with } n = hkl \qquad (1)$$

θ is half the deflection, n is the integer called "Diffraction Order" and hkl are the Miler indices representing the diffraction peak planes. The various diffractograms of the raw material

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powders presented were obtained on a Brucker-AXS D 5005 Debye-Sherrer apparatus, using Cu Kα radiation (λ Kα = 1.54056 Å) and a graphite back monochromator. The analysis range is between 5 and 70° with a step size of 0.04° and an acquisition time of 2s. The crystalline phases present in the material are identified by comparison with the PDF (Powder Diffraction Files) standards of the ICDD (International Centre for Diffraction Data).

2.4. Measurement of physical properties of samples

2.4.1 Specific surface area of BET raw materials

The specific surface area or mass area of a powder is the total surface area per unit mass. It governs the reactivity of powders. The measurement of the specific surface allows to determine the surface or the totality of the surface of the particles including that of the open pores accessible to the molecules of external gas. It is based on the measurement of the quantity of gas adsorbed (nitrogen) by a powder sample. From the amount of absorbate, the size of the adsorbed molecules and their arrangement possibilities, the surface of the solid responsible for the adsorption is evaluated using the so-called BET calculation model (Brunauer, Emmett and Teller). The BET method requires a pre-treatment of the samples (degassing and dehydration between 150 °C and 300 °C) in order to evacuate all the molecules previously adsorbed by the solid. The apparatus used is Micromeritics Flow Sorb ASAP 202.

2.4.2 Measurement of Absolute Densities of Raw Materials

Absolute density is the ratio of the mass of dry material to its actual volume, understood as the volume of solid material in a porous body (Normes ISO et al. 1983). The absolute densities of raw materials were measured using Malvern Instruments Ltd (Mastersizer 2000 Ver. 5.22). The principle of this technique is based on the measurement of the pressure P_1 prevailing in a calibrated chamber and the pressure P_2 of the cell containing the sample. This technique is based on Mariotte's law, equation (2):

$$V_{ech} = V_{cell} - \frac{V_{exp}}{\frac{P_1}{P_2} - 1} \qquad (2)$$

The volume of the cell (Vcell) and the expansion volume (Vexp) are constants given by the manufacturer. The determination of the volume of the sample, Vech, allows to calculate its density. After calibrating the pycnometer with a steel ball of known mass and volume, a small quantity of sample dried in an oven at 105 ±5 °C for 24 hours is placed in a cell and then introduced into the apparatus. The helium pressure is set to 1.8 bars, and the apparatus automatically performs 5 measurements of the particle volume and calculates the average

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volume (in cm^3). In relation to the dry mass (in g) of the sample initially recorded in the apparatus, the average density is displayed (g/cm^3).

2.4.3 Time of beginning and end of setting

The time of beginning of setting corresponds to the moment when there is an increase in viscosity, or stiffening of the cement paste, which is measured by means of the standard needle of the VICAT Apparatus, according to ASTM C191-13 standard. It corresponds to the time elapsed from the mixing of the cement paste to the moment when the needle stops at a distance d from the bottom of the 40 mm high ring filled with pure cement paste under a 500 g load. The tests are performed at laboratory temperature (24 ± 3 °C). To conduct a test, the mixing of the paste is divided into several steps: mixing for 1 minute at slow speed, stopping the mixer during and scraping the walls of the mixer bowl then mixing for 2 minutes at fast speed and manual scraping before pouring the paste into the truncated cone mould. Every 15 min, the needle initially placed on the surface of the truncated cone is dropped until the needle stops at a distance d= 4mm ± 1 mm from the bottom of the ring. The time of the end of the setting is the time at which the needle sinks only 0.5 mm.

2.4.4 Measurement of linear shrinkage

Shrinkage is a reduction in length of a specimen caused by drying. The test consists in following the evolution of the dimensional changes of a specimen of normal mortar kept in air. Linear shrinkage (LRS) measurements are made using a Mitutoyo digital caliper on prismatic specimens maintained at laboratory temperature (24 ± 3 °C). This apparatus is equipped with a comparator which is set to zero just at the time of the demoulding of the specimen on the 160mm long invar rod, i.e. L0 the measurement of the specimen. We designate by the value read on the comparator at the considered ages (7 and 28 days), the length of the specimen is given by the equation (3).

$$L(t) = Lo + dL(t) \qquad (3)$$

$L(t)$: Length of the specimen at time t (which differs from 160 mm because of the defects of the mould).

dL(t): difference between the theoretical length of the mould (160mm) and its real length. For each specimen, the linear shrinkage at the dates below 7th and 28th days is given by the equation (4).

$$RL = \frac{L(t_0) - L(t)}{L(t_0)} \qquad (4)$$

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2.4.5 Water absorption and bulk density

Measurements were made according to (ASTM C 642-06 Standard et al., 2013). After soaking in water for 24 hours, the sample was spread out on a flat non-absorbent surface and subjected to a flow of hot air (steaming), while stirring it so that the outer surface of the grains would dry. This drying was done in a gentle manner so as not to remove water that could be trapped inside the aggregate. The grains are then free of any capillary attraction forces. The percentage of water absorption (Abs) is defined by the equation (5):

$$Abs\ \% = \frac{Mh - Ms}{Ms} \times 100 \qquad (5)$$

$\boldsymbol{Ms}$ =mass of the dry sample after oven drying at 105 ±5 °C for 24 hours in gram (g).
$\boldsymbol{Mh}$ =mass of the sample soaked with water for 48 hours in gram (g).
The bulk density is obtained by taking the masses of the samples individually and their various corresponding volumes. It is the mass of a constant $\boldsymbol{Ms}$ body after oven drying at 105 ±5 °C for 24 hours, noted per unit apparent volume in the natural state $\boldsymbol{Vap}$, and expressed in g/cm3 relation (III-6).

$$\rho = \frac{Ms}{Vap} \qquad \text{(III-6)}$$

With Ms in g; $Vap = Lb^2$ in cm^3 where L and b represent respectively the length and the side of the specimen in cm.

2.5. Measurement of mechanical properties of products

The measurement of mechanical properties of a standardized mortar is carried out according to EN 196-1 (Methods of testing cement 1998) at the end of mechanically characterized a cement in accordance with the standard NF P 15-301 (Liants hydrauliques 1994).

2.5.1. Flexural tensile strength

The flexural tests are carried out on the flexural apparatus by placing the specimen symmetrical and centred on the plate then a continuous load is applied to the specimen at a speed of 0.001 MPa/s until failure and the reading of the load is made (Figure III-9a). The bending strength Rf is given by the following expression (5).

$$Rf = \frac{1{,}5 \times F \times L}{b^3} \qquad (5).$$

F is fracture force at flexion;
L is the length of the specimen

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2.5.2. Compressive strength

The compressive strength (Rc) is measured by crushing one half of the prismatic mortar specimen subjected to bending in the ambient atmosphere of the laboratory. The compressive strength is the quotient of the maximum load borne by the specimen during the test by its initial cross-section. For each formulation, the strength obtained is the average of the tests performed on three specimens. The test consists in placing the specimen on the plate of an electro-hydraulic press (Instron 1195 compression machine). It is then subjected to a continuous and progressive load at an average speed of 0.5 MPa/second until it is crushed. The surfaces of the samples were polished flat to avoid non-uniform loading. By designating by b the side (measured with the caliper) of the prismatic specimen and by Fm the maximum load it supports until failure, RC is calculated according to the relation (6).

$$R_C = \frac{Fm}{b^2} \quad (6)$$

3. Results and Discussions

3.1. Mineralogical analyses by X-ray diffraction

The figures 3 and 4 show the nature of the crystalline phases present in the clinker and Loum natural pozzolan which were determined by X-ray diffraction (XRD) on the disoriented powders. The clinker diffractogram shows the presence of oxides such as portlandite, calcite, belite, stratlingite, dicalic aluminate hydrate, tetracalcium aluminate hydrate and tetracalcium aluminoferite.

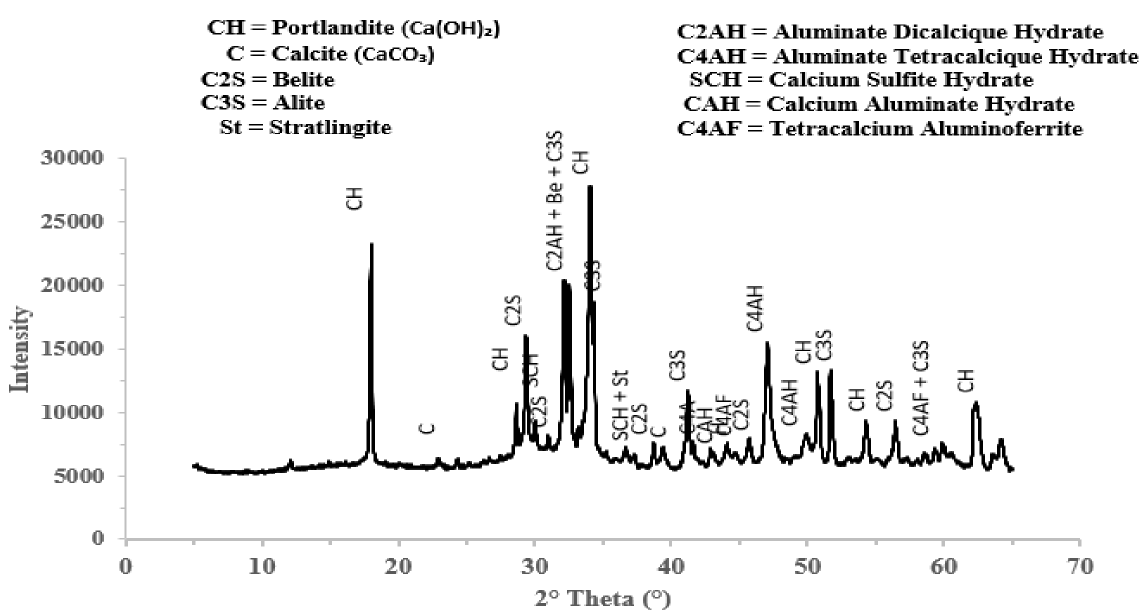

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Figure 3: X-ray diffractogram of clinker

The diffractogram of the natural pozzolan reveals the presence of Cristobalite, Quartz, Illite, Anorthite, Muscovite, Anthophyllite, Albite, Augite, Magnetite and Hematite. The presence of quartz in this pozzolan confirms the presence of the mineral phases found in the samples. It indicates the absence of feldspathoids such as leucite; pollicite; analcime; sodalite, etc. which are silicates close to feldspars but containing less silica (Billong et al., 2013). Therefore, the coexistence of these minerals with free silica (quartz) is impossible. The basic profile of XRD patterns of natural pozzolan indicates the presence of a considerable amount of glassy phases in the samples. From the work of Millet et al. (1977) concerning natural pozzolans, it was noted that the area of the diffraction band due to the presence of glass in the slag is directly proportional to the amount of glassy phase in the samples. The rapid cooling of the magma in the atmosphere during the volcanic eruption is the cause of the glassy phase in pozzolans of volcanic origin. Millet et al. (1977) have also shown that the glassy phase content of pozzolans is related to the SiO_2 and CaO content in the sample, the difference between the two being greater than or equal to 34%. After calculating this difference for the natural pozzolan sample using the data in Table 1, we obtained 35.67%. This is a confirmation of the presence of the glassy phase in the volcanic pozzolans studied. The presence of this glassy phase would play a major role in the reactivity of the pozzolan sample in the presence of Ca $(OH)_2$ and water to form a pozzolanic bond or in the presence of NaOH or KaOH and water to form a binder.

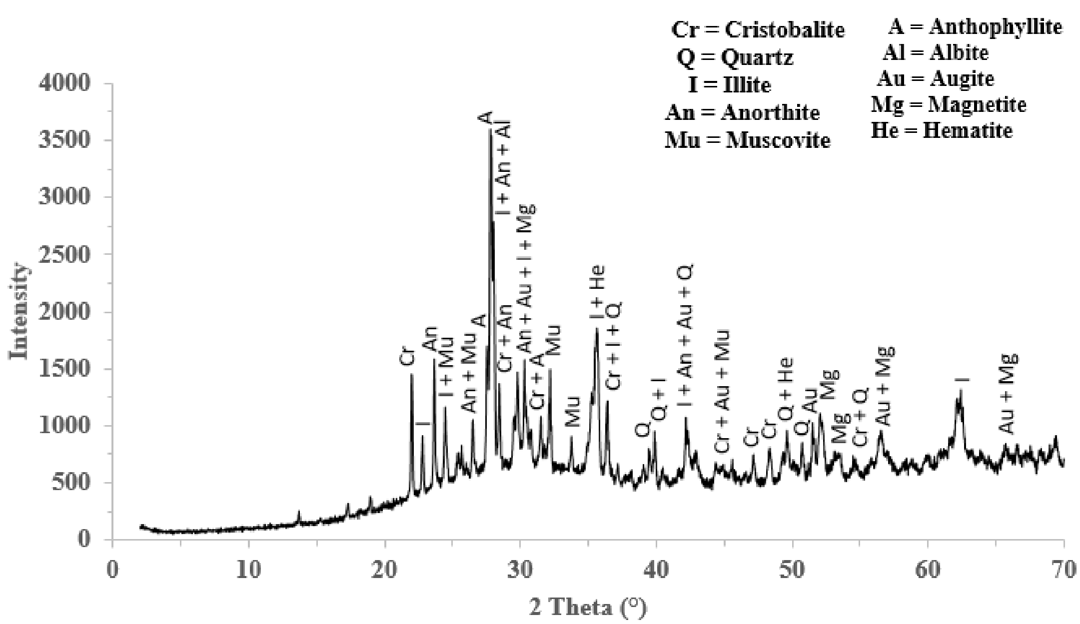

Figure 4: X-ray diffractogram of Loum natural pozzolan.

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3.2. Physical properties: BET specific surface areas and absolute densities

The measurements of specific surface areas and absolute densities show that pozzolan has a higher specific surface area than clinker while its absolute density is lower than the latter. These values are respectively equal to 1.52 m^2/g and 2.872 g/cm^3 for natural pozzolan and 0.318 m^2/g and 3.14 g/cm^3 for clinker (Table 1). These properties can influence in one way or another on the mechanical behaviour of products including the bulk density, water absorption and mechanical strength.

Table 1: Specific surfaces and absolute densities of raw materials.

Samples	**Specific surfaces (m^2/g)**	**Absolute densities (g/cm^3)**
Pozzolan	1,52	2,872
Clinker	0,318	3,14

3.3. Start and end times

The variation of the initial and final setting time of the pastes as a function of the substitution rate of clinker by pozzolan (Table 2 and Fig. 5) display the different values. It was found that the initial and final setting time increased with the addition of pozzolan to the pastes compared to those with no addition (Tchedele et al., 2020) made the same observation when substituting cement with ground glass powder. Thus, for a partial substitution of clinker in the range of 0-40% by pozzolan, the initial and final setting times varied from 124-208 min and 181-254 min respectively, which confirms that at young ages, setting is faster for the clinker paste because the influence of the pozzolan had the effect of delaying the hydration of the cement. This retarding effect can be attributed to the decreasing cement content with the auxiliaries. These times correlate with the consistency of each cement sample, as the higher the consistency, the longer the setting time. From the point of view of the setting time, all these cements comply with NF EN 196-3 and NC 235: 2005-06, which prescribe that this time be greater than 60 min.

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Table 2: Start of take and end of plug

% of Loum natural pozzolan	**Start of take**	**End of plug**
0%P	124	181
10%P	162	205
20%P	168	237
30%P	196	240
40%P	208	254

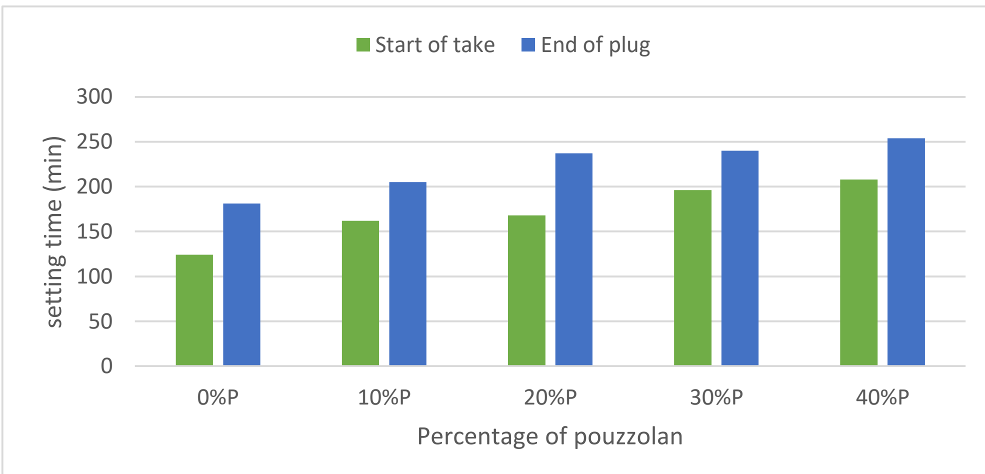

Figure 5: Setting time of the pastes with addition of water

The linear shrinkage at 28 days of hardening of the mortars according to the pozzolan proportions (Table 3 and Fig. 6) gives the different values obtain. A slight shrinkage of the specimens is observed during curing and drying. At 28 days of curing, this shrinkage was less than 0.2 % in all the samples, which is in accordance with the NF P15-433 standard. For the developed specimens, there was an increase in shrinkage as the pozzolan content increased. This can be explained by the decrease in the number and diameter of pores in the hydrated cement paste, as well as the formation of a secondary HSC. For the specimens containing 10 and 20% pozzolan, the shrinkage was almost similar, showing the equilibrium of the C/E ratio.

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Table 3: average linear shrinkage of mortars at 28 days

% of Loum pozzolan	**(%)linear shrinkage at 28 days**
0%P	0.0914
10%P	0.0974
20%P	0.1083
30%P	0.1271
40%P	0.149

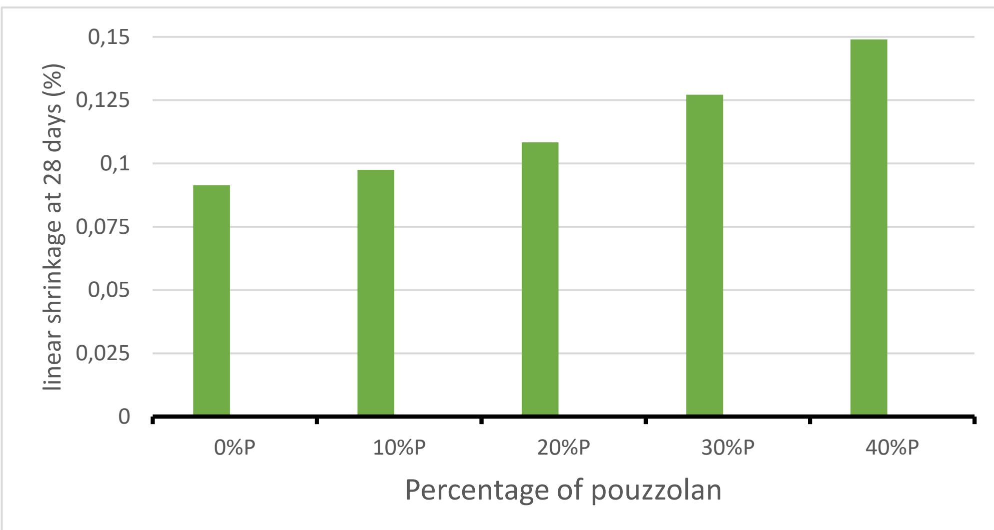

Figure 6: average linear shrinkage of mortars at 28 days

3.4. Water absorption and Bulk Density

3.4.1 Water absorption

The capillary absorption rate is significantly influenced by the binder combination used (Deboucha et al., 2017). It plays an important role in the durability of materials. Table 4 and Figure 7 show the water absorption rate of the specimens decreasing when the percentage of pozzolan increases in the mortars. This is in agreement with the observations made by Deboucha et al. (2017), who showed that the water absorption coefficient of capillary mortar is improved by using 40% natural pozzolan instead of clinker and the absorption values

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decrease as the metakaolin content in the concrete is increased (Deboucha et al., 2017). This decrease in absorption is due to the greater fineness of the different admixtures compared to cement (Figmig et al., 2021). Pozzolans fill the pores in the bulk paste or in the interfaces between the aggregate and the cement paste. They can therefore be considered as mineral admixtures. The results also show that the pozzolan improves the water absorption rate. Absorption rates of 5%; 4.65%; 4.46% and 4.29% were recorded at different percentages of pozzolan substitution. This improvement is justified by the higher specific surface area of the pozzolan. Some studies have shown that the absorption rate can decrease with curing time. This could be explained by the densification of the microstructure due to the hydration process (S. Kolias and C. Georgiou, 2005).

Table 4: Water absorption of mortars

% of Natural Pozzolan	Water absorption in %
0%P	5.0821
10%P	5.0031
20%P	4.6475
30%P	4.4611
40%P	4.2908

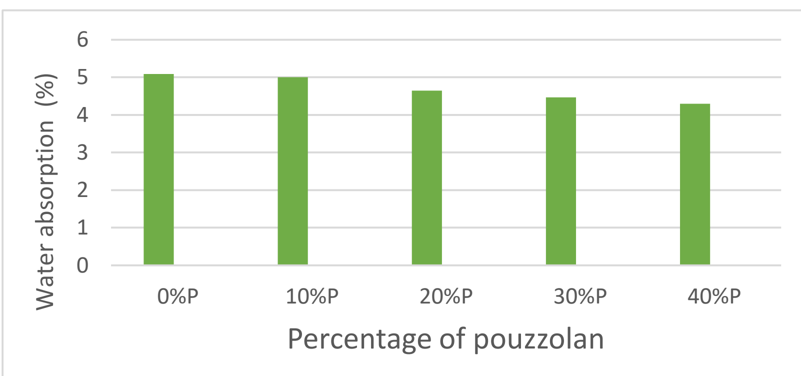

Figure 7: Water absorption of mortars.

3.4.2 Bulk density

The density is the amount of material packed into a given space. This property decreased with the rate of pozzolan substitution (Table 5 and Fig. 8). The trend is consistent with the water absorption results. Pozzolan particles are less dense compared to clinker (2.872 g/cm^3

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for pozzolan and 3.14 g/cm^3 for clinker) as they modified the compactness of the mixes and contributed to decrease the bulk density of the hardened mortar. The mortar containing 10% pozzolan has a bulk density very close to that of the mortar with clinker so their longer term behaviour would be necessary for a good comparison. The lowest value of the densities is 2178 kg/m^3 obtained at 40% pozzolan substitution which is compatible with the results obtained in compression.

Table 5: Apparent density of mortars at 28 days

% of Natural pozzolan	Apparent density (kg/m3)
0%P	2214
10%P	2213
20%P	2198
30%P	2182
40%P	2178

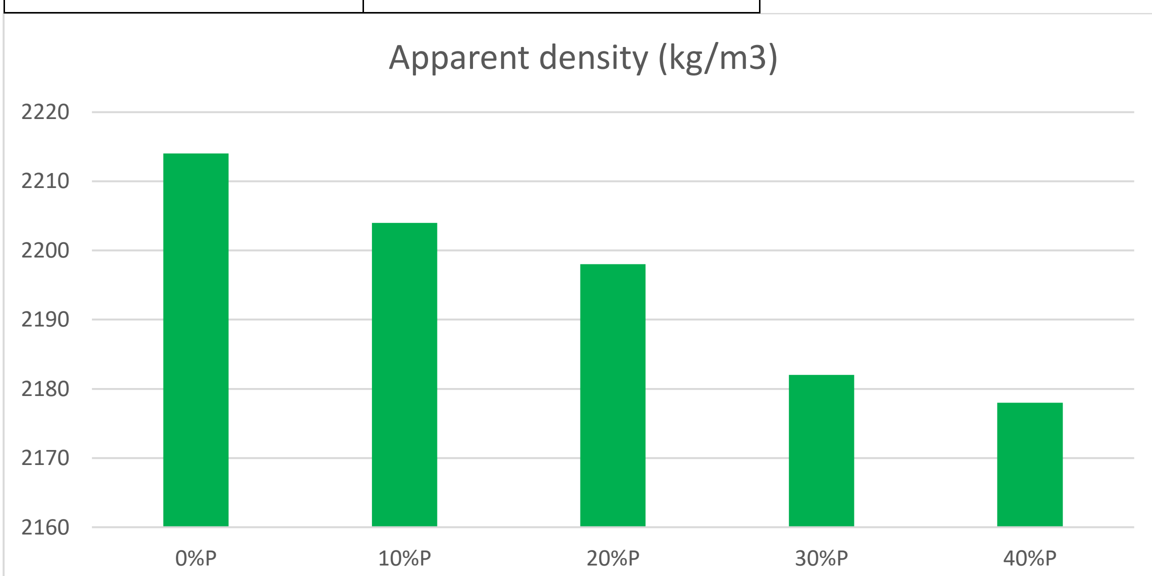

Figure 8: Apparent density of mortars at 28 days.

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3.4. Mechanical resistance

3.4.1 Flexural Tensile Strength

Table 6 and Figure 9 show the effect of pozzolans on the flexural strength of mortars at the different ages of 7 and 28 days. Systematic reductions in the strengths of the mortars at the different ages are observed as the percentage of pozzolan increases. It is observed that the strength reduction rate of mortars with pozzolan addition compared to mortar with clinker tends to decrease considerably at young age and tends to increase at day 28. This reduction increases from 12.25% to 46.75% at young age and from 4.17% to 30.42% at 28 days. This is due to the pozzolanic activity of the addition which is low at young age. This fact could be explained by the physicochemical effect of the different mixtures (Noui and Zeghichi., 2017). A similar phenomenon was observed by Benkaddour et al. (2009), in their work on the durability of mortars based on natural pozzolan and artificial pozzolan which showed that the pozzolanic reaction is not predominant at young ages, which leads to a less intense hydration at young ages inducing low resistances (set retarder effect (Benkaddour et al., 2009).

Table 6: Flexural strength at 7 days and 28 days

% of Natural pozzolan	**7 days (MPa)**	**28 days (MPa)**
0%P	7.28346	8.4284
10%P	6.39156	8.0766
20%P	5.68135	7.7667
30%P	5.06733	6.9549
40%P	3.878334	5.86474

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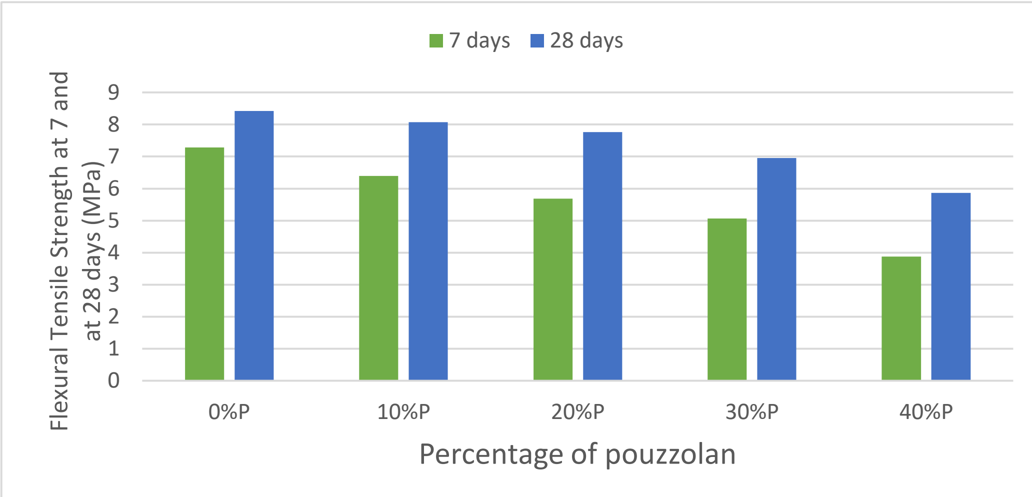

Figure 9: Flexural strength at 7 days and 28 days

3.4.2 Compressive strength

The table 7 and Figure 10 exhibit the development of compressive strengths for the different mortars at different percentages of cement substitution by Loum pozzolan at 7 and 28 days. The compressive strength increases with time for all mortars but decreases with increasing pozzolan content which is identical to the observations made by Deboucha et al. (2017) et Celik et al. (2014). This kinetics can be explained by the dilution phenomenon caused by the partial replacement of cement, where the higher the substitution rate, the less hydrates are formed (Belguesmia et al., 2018). The mortar without addition after 7 and 28 days of curing offers a compressive strength of 32.45 and 50.93 MPa respectively. These strengths are higher than all the strengths of mortars with pozzolanic addition except for the mortar with 10% at 28 days which offers a very close strength. This observation is similar to that of Malagavelli et al. (2018), who obtained a higher strength at 10% Metakaolin substitution than the mortar containing 0% Metakaolin (Pastariya and Lohar, 2020). The drop in strength may be due to the fineness of the pozzolan used which is higher than that of the substituted clinker as Cyr et al. (2006) have shown that as the fineness of an admixture increases the physical effect of its grains takes part in the hydration process where hydrates take the admixture particles as a nucleation site which catalyses the hydration of the cement grains (Cyr et al., 2006).

The mortar with 40% pozzolan has a strength of 26.94 MPa at 28 days. This drop in strength can be attributed to the insufficient amount of lime released during cement hydration and consequently to incomplete chemical reactions. Under the compressive strength criterion,

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and in accordance with NF P 15 301, it can be said that cements containing 40% pozzolan do not meet the classification criteria, so for normal substitution one should limit the content to 30%. This 10% pozzolan counterpart recorded a strength of more than 42.5 MPa at 28 days which could be considered as a class 42.5 Portland cement. This explains the fact that this percentage can contribute to the hydration kinetics hence the existence of two types of calcium silicate (CSH) in cement-based systems with additives (Oudjit et al., 2007) whose density can have a significant effect on the mechanical properties of the mortar (Vandamme et al., 2010). The properties of the latter can affect the macroscopic behaviour of mortar and concrete. However, up to 30% pozzolan is recorded as having a higher strength of 32.5 MPa at 28 days, which allows it to be assigned to class 32.5.

Table IV. 7: Compressive strength at 7 and 28 days.

% of Natural pozzolan	**7 days (MPa)**	**28 days (MPa)**
0%P	32.4553	50.9378
10%P	27.9646	49.9578
20%P	22.9261	37.0267
30%P	19.8707	34.0572
40%P	17.9279	26.9453

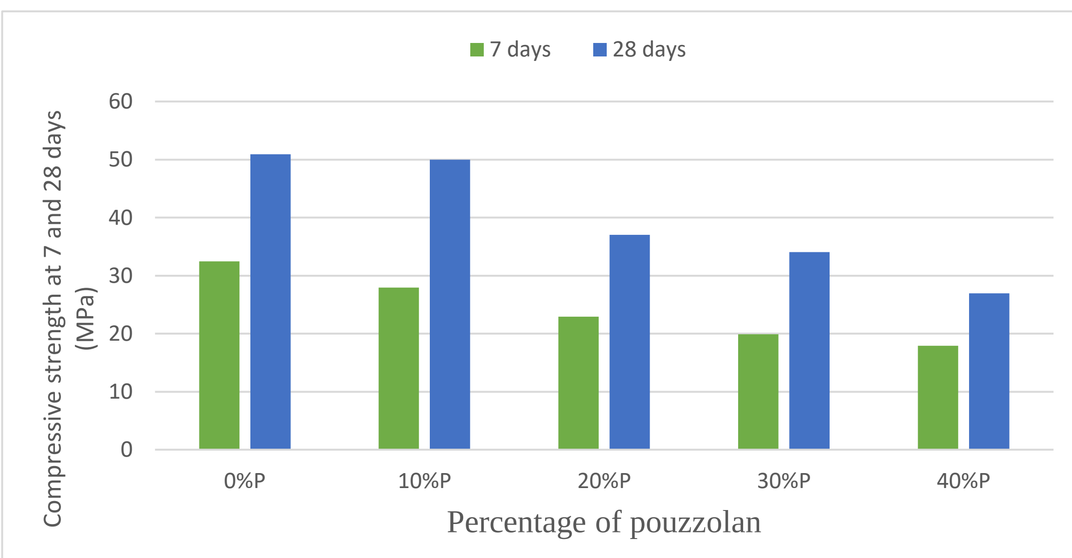

Figure 10: Compressive strength at 7 and 28 days.

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4. Conclusion and recommendations

The characterization of the raw materials (Portland clinker and natural pozzolan) was done before the formulation test of the paste and mortar specimens. The results obtained in this mineralogical and physical study show that: (1) the ratio of the compressive strength to that measured at 28 days (with 10% natural pozzolan a strength higher than 42.5 MPa is recorded which could be considered as a class 42.5 Portland cement), increases with time, especially for mortars with pozzolanic addition. This reaction produces additional C-S-H gels which contribute to the improvement of the pore filling in the mortar, then increases the mechanical strength. (2) the water absorption rate of the specimens decreases when the percentage of pozzolanic content increases in the mortars, which allows us to increase the quantity of mixing water as the pozzolanic content increases leading to a constant workability. (3) Furthermore, this reduction in water absorption is due to the greater fineness of the various additives compared to cement, they can therefore be considered as mineral additives to delay the setting of the pozzolanic mortar, which is beneficial for the delivery of concrete over a considerable distance, (4) a better value of thermal conductivity as a function of time and when compared to mortars with Portland clinker preserved in water for the same age. From this, a better thermal insulation is deduced.

The pozzolan studied here is a natural product and therefore does not go through expensive industrial processes. It is much cheaper and less toxic than Portland clinker, which goes through very expensive processes and produces carbon dioxide in large cement companies, destroying and polluting the atmosphere. The use of natural pozzolan as a substitute for clinker for cement manufacturing is recommended for the following advantages: (1) of achieving acceptable performance in terms of compressive strength, capillary absorption and thermal properties, (2) higher strengths and less cost compared to Portland cement, therefore recommended both for companies (cement producers) and consumers in Cameroon and neighboring countries.

As the literature is poorly documented on the thermal characteristics of mortars containing natural pozzolan, there is an urgent need for an experimental study on the thermo-physical (e.g: thermal conductivity, thermal resistance) and chemical (e.g: chemical analysis by X-ray fluorescence spectrometry, Infrared Spectroscopy) properties of mortars based on different percentages of natural pozzolan in order to define the optimal dosage that gives the mortar the best characteristics. Also, pozzolanic mortars can be recommended as thermal insulating materials because the thermal conductivity of the samples is low as a function of time and as the pozzolan content increases. Hence, the energy efficiency of these materials.

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