Global Journal of Engineering and Technology Advances
eISSN: 2582-5003
Cross Ref DOI: 10.30574/gjeta
Journal homepage: https://gjeta.com/

(RESEARCH ARTICLE)

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Comparative study of the effects of a natural pozzolan and an artificial pozzolan on the hydraulic properties of Portland cement mortar

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Global Journal of Engineering and Technology Advances, 2023, 14(01), 107–119

Publication history: Received on 14 December 2022; revised on 25 January 2023; accepted on 27 January 2023

Article DOI: https://doi.org/10.30574/gjeta.2023.14.1.0021

Abstract

The comparative study of some effects of natural and artificial pozzolans on the hydraulic properties of Portland cement mortar is performed in this work. The natural pozzolan used coming from the Djoungo deposit, Moungo department in the Littoral region (Cameroon) was finely ground and then sieved at 100 µm. The artificial pozzolan used is the alluvial clay of Etoa collected from Yaoundé III District in Mfoundi Division of the Centre Region of Cameroon. It was thermally activated at 700°C after grinding and sieving. The chemical and mineralogical analysis of the raw materials were studied by X-ray fluorescence, infrared spectrometry (FTIR) and X-ray diffraction (XRD) then the specific surfaces and the absolute densities were determined. The formulation of the pastes and mortar was obtained by substituting Portland cement with different pozzolans at different percentages, while the initial and final setting time of the fresh pastes were determined. Linear shrinkage, water absorption, apparent density, flexural strength and compressive strength tests at 7 and 28 days were determined on the hardened mortars. The results obtained show an increasing in the initial and final setting time with the addition of the amount of pozzolan (natural or artificial), the pozzolans played the role of setting retarder in the mixtures, finer particles of the artificial pozzolan speed up the setting time of pastes as compared to that with natural pozzolan. The shrinkage of the hardened mortars increased with the addition of the pozzolans, but it was less than 0.2% in all the samples, the specimens with artificial pozzolans were more affected by the drying shrinkage. The mortars had good mechanical resistance but from 30 to 40% pozzolan, whether artificial or natural, the resistance dropped, the dilution phenomenon caused by the partial replacement of the cement was responsible for the drop in resistance with the addition of pozzolans. The water absorption rate and the apparent density of the specimens decrease when the percentage of pozzolan increases in the mortars. Artificial pozzolan offers a better water absorption rate compared to natural pozzolan due to its higher specific surface. Natural pozzolan makes it possible to obtain a denser mortar.

Keywords: Portland cement; Pozzolan; Clay; Hydraulic properties

1. Introduction

The increasing in population, infrastructure and economic activities, particularly in developing countries, leads to a growing demand for building materials, among which the most used is concrete, with cement as its main constituent [1]. Portland cement production in the world is around 1.2 billion tons per year [2]. Each ton of ordinary Portland cement is known to produce a similar amount of carbon dioxide in the atmosphere, a major greenhouse gas implicated

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in global warming, which makes the cement industry responsible for about 7% of global carbon dioxide emissions [3] Additionally, cement undergoes hydration in the form of calcium silicate hydrate. calcium as well as calcium hydroxide (lime) free lime tends to cause expansion in concrete, which makes the concrete prone to premature failure and inhibits its durability properties [4]. Challenges of the cement industry nowadays are the replacement (20 - 50%) of Portland cement by pozzolanic materials [5]. Recent developments on ternary cement that are integrated in certain industrial wastes, natural resources such as limestone, pozzolan and clay judged as additional cementitious properties [6, 7]. According to Jing Hao-Liang et al. [8], OPC clinker could be mixed with roasted clay and limestone powder to produce low-cost mixed cement with minimal environmental pollution. Several researchers had worked on the use of supplemental cementitious materials as partial replacement for cement in mortar and concrete [9-12]. These r Cementitious Materials are part of the production of durable, high-strength concrete, having the ability to react with the lime produced from the hydration of cement, thus forming Supplemental Calcium Silicate Hydrate (CSH) [13]. The introduction of these natural resources in the cement presented environmental advantages due to the reduction of the cost of production, the minimization of the CO_2 emissions in the atmosphere [14, 15] and the recovery of raw materials. It should be noted that most of the substitute materials have a pozzolanic behavior.

Pozzolans can be natural or artificial. Natural pozzolans come from volcanic eruption and can be either volcanic ash or volcanic pumice. Artificial pozzolans are obtained following the thermal treatment of industrial waste or clay materials including: metakaolin (MK), fly ash (FA), silica fume (SF), rice husk ash (RHA) and granulated ground blast furnace slag (GGBFS) [1]. The cements obtained from the substitution of CPA by natural pozzolana have low resistance compared to CPA but play a setting regulator role [16]. The technical advantages of pozzolans in concreting could be attributed to the presence of an abundant amount of alumina or silica which tend to improve the process of hydration of the cement and consequently a better improvement in the resistance with a development remarkable microstructural structure [17]. Metakaolin is quite different from other man-made pozzolans because it comes from a heat treatment process involving the removal of water and the phase change of the hydroxyl present in porcelain clay called kaolin [18, 19]. In the present study, investigation was carried out on the comparative study of the effects of a natural pozzolan and an artificial pozzolan on the hydraulic properties of mortar Portland cement.

In the present study, investigation was carried out on the comparative study of the effects of a natural pozzolan and an artificial pozzolan on the hydraulic properties of Portland cement mortar.

The chemical, mineralogical and physical characteristics of raw materials were determined, and then the initial and final setting time of fresh pastes was tested. Hardened mortars underwent linear shrinkage, water absorption, apparent density, Flexural strength and compressive strength at 7 and 28 days tests.

2. Material and experimental methods

2.1. Materials

The cement used is artificial Portland cement CPA (without addition) of type CEM-I 42.5 R supplied by the company CIMENCAM, a local factory. The sand is siliceous in nature with rounded grains of dimension less than 2 mm coming from the Sanaga river having undergone a granular correction in order to have a continuous granulometry in accordance with the normalized sand spindle prescribed by Standard EN 196-1.

The sample of natural pozzolan comes from the Djoungo deposit in the Moungo department, Cameroon Littoral region taken in the area of geographical coordinates, X = 9 ° 37'32 '' East longitude and Y = 4 ° 35'16 '' North latitude . It was oven dried for 24-105 °C then ground and dry sieved at 100 µm for storage.

The artificial pozzolana used is the thermally activated clay (AAT) which results from the firing at 700 ° C of the alluvial clay of Etoa in Yaoundé III District, Mfoudi Division, Centre Region of Cameroon, taken from the area with geographical Coordinate X = 11 ° 27 'East longitude and Y = 3 ° 45' North latitude. After sampling, the clay was dried in an oven at 105 °C for 24 hours then crushed and dry sieved at 100 µm. The calcination was carried out in an Enitherm electric furnace in small quantities, depending on the capacity of the furnaces available. The cooking operation required certain precautions: to avoid thermal shock. The cooking speed was set at 3 °C / min, the cooking temperature (700 °C) was kept constant for 5 hours.

The chemical composition of these materials shown in Table 1 was performed by the X-ray fluorescence method using a Panalytical type spectrometer. The major oxides (over 10% by weight) are silica, alumina and iron for pozzolans and silica and calcium for CPA. Pozzolans have a very low MnO content. The results show that the artificial pozzolan conforms to the specifications of the ASTM C 618 standard and the Indian standard [20]

Table 1 Chemical composition of raw materials

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_2	LOI
PN	45.64	15.44	12.81	9.97	6.76	3.88	1.03	2.43	0.2	0.55	0.20
PA	56.58	21.81	9.26	0.03	0.03	0.10	0.74	1.95	0.01	0.15	3.11
CPA	16.72	3.23	4.91	68.90	1.12	0.19	0.97	0.251	0.06	0.46	0.87

Fourier transformed infrared spectroscopy analyses was made with an Avatar 330 FTIR, Thermo Nicolet 5700 equipment, analyzing surface and bulk area was used for FTIR. A minimum of 32 scans between 4000 and 400 cm^{-1} was averaged for each spectrum with 1 cm^{-1} resolution, in order to determine the mode of vibration of the particles present in the materials. These spectrograms are shown in Figures 1, 2 and 3 respectively for Portland cement, natural pozzolan and artificial pozzolan. The Portland cement spectrum shows an absorption band of 3648 cm^{-1} attributable to the OH bond vibration mode, on the other hand the bands centered at 1473, 2037, and 650 cm^{-1} reflect the calcium-carbonate vibration mode (Ca-O) and bands 1117; 878; 518 cm^{-1} reflect the mode of vibration of the Si-O bonds; Al-O and Si-O-Al.

Figure 2 shows the absorption bands of 1542 and 3450 cm^{-1} which express respectively the deformation vibrations of the H-O-H valence bonds and the OH bonds of water molecules [21]. The absorption band of 939 cm^{-1} corresponds to the symmetrical and asymmetrical elongation vibrations of the Si-O-Si or Si-O-Al bonds, while the band at 706 cm^{-1} reflects the presence of the elongation vibrations. Of Al-O where Al is in coordination VI. The bands at 939 cm^{-1} and 537 cm^{-1} observed indicate the presence of sorosilicates (Si2O7) 6- with a partial substitution of Si4 + by Al3 + in the tetrahedral position. These bands also express the internal vibrations of (SiO4) 4- and (AlO4) 5- in the tetrahedral sites: The first (930 cm^{-1}) results from symmetrical and antisymmetric elongation vibrations of Si-O-Si or Si- O-Al while that at 537 cm^{-1} is attributable to the deformation vibrations of the O-Si-O bonds. Finally, the absorption band at 424 cm^{-1} indicates the presence of the straining vibration of the O-Si-O bonds.

Figure 3 shows the different absorption bands of artificial pozzolana. There is a weak absorption band of 3562 cm^{-1} corresponding to the vibration mode of the Al-OH bond, indicating the completion of the transformation of kaolinite to residual kaolin. That around 2060 cm^{-1} is assigned to the vibrational elongation of the C-O bond. The long band centered at 1058 cm^{-1} is typical for the formation of the amorphous phase formed after calcination. It reflects the vibration modes of the Si-O-Al bond. The bands centered around 779 and 449 cm^{-1} reflect the Si-O, Al-O and Si-O-Al bond vibration modes.

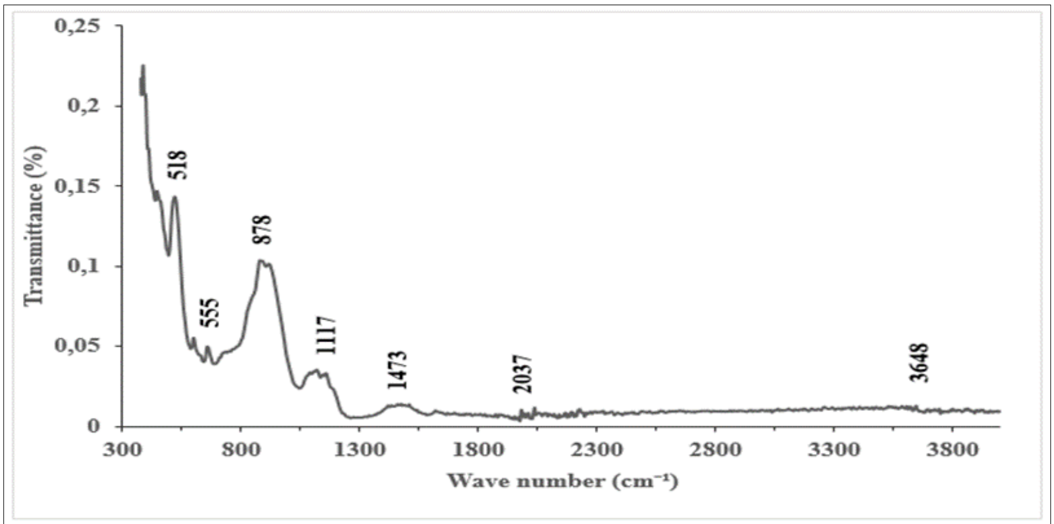

Figure 1 Infrared Spectrogram of artificial Portland cement

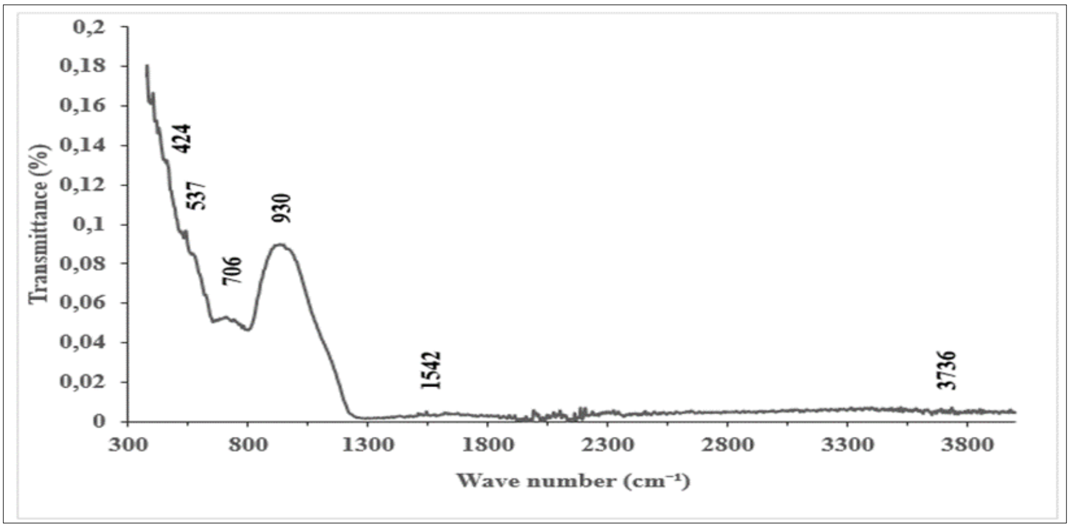

Figure 2 Infrared spectrogram of natural pozzolana

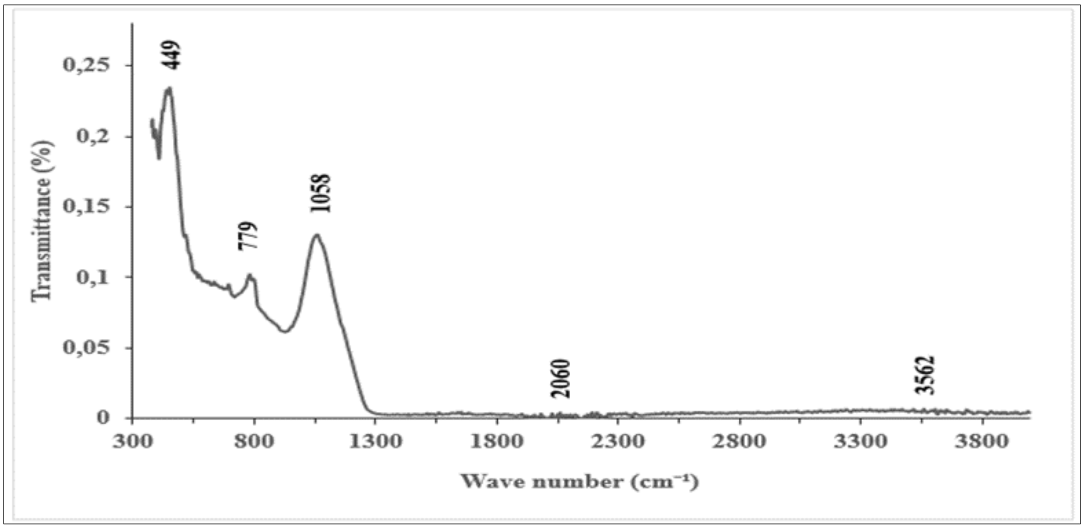

Figure 3 Infrared spectrogram of the artificial pozzolana

The ray materials were crushed and submitted to X-Ray Diffractometry (XRD). A Bruker-AXS D 5005 equipment with a CuKα radiation source (λ = 1, 54056 Å), an acceleration voltage of 40 kV and current of 40 mA was used for X-ray diffraction (XRD) mineralogical analysis. The results in

Figures 4, 5 and 6 are shown the nature of the crystalline phases present in Portland cement (CPA), natural pozzolan (NP), and artificial pozzolan (AP). They show the presence of oxides such as Portlandite, calcite, belite, alite, stratlingite, dicalcium aluminate hydrate, tetracalcium aluminate hydrate, calcium aluminate hydrate and tetracalcium aluminoferrite in CPA. The diffractogram of the natural pozzolan reveals the presence of Cristobalite; Quartz; the Illite; Anorthite; Muscovite Anthophyllite; albite; the 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; pollicitis; analcime; sodalite; etc. which are silicates close to feldspars but containing less silica [3]. The basic profile of XRD patterns of natural pozzolan indicates the presence of a considerable amount of the glassy phases in the samples. Figure 6 indicates the presence of muscovite, quartz, illute and anatase as minerals in artificial pozzolan. Ndigui Billong et al., [3] observed the presence of kaolinite, quartz and hematite as main minerals in this clay. The absence of the kaolinite peak is justified by the transformation of its crystal structure into an amorphous state following activation at 700 ° C of the clay sample.

Measurements of specific surfaces and absolute densities show that pozzolans have a higher specific surface than CPA while their absolute densities are lower than CPA. These values are respectively equal to 1.52 m^2 / g and 2.872 g / cm3 for natural pozzolan, 21.31 m^2 / g and 2.724 g / cm3 for artificial pozzolan then 0.318 m^2 / g and 3.14 g / cm3 for Portland cement.

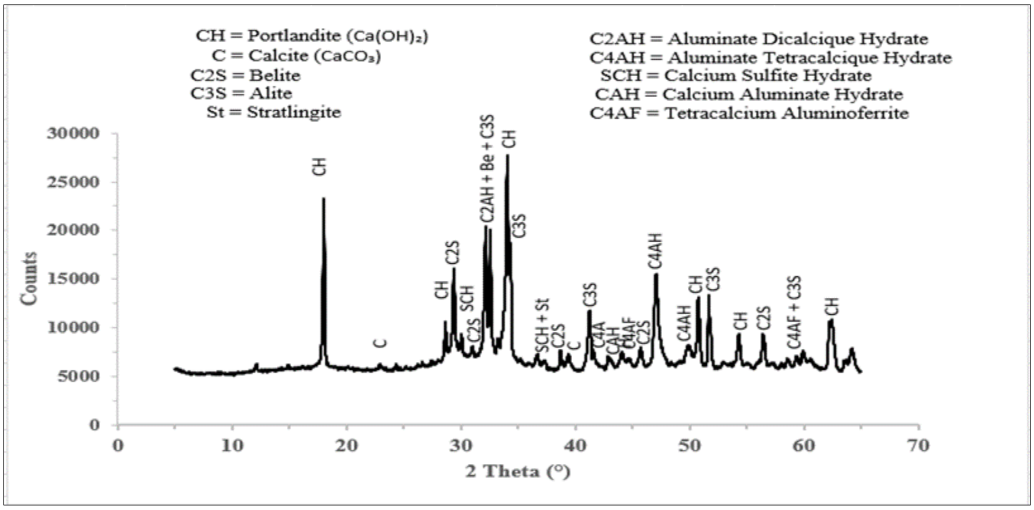

Figure 4 CPA X-ray diffractogram

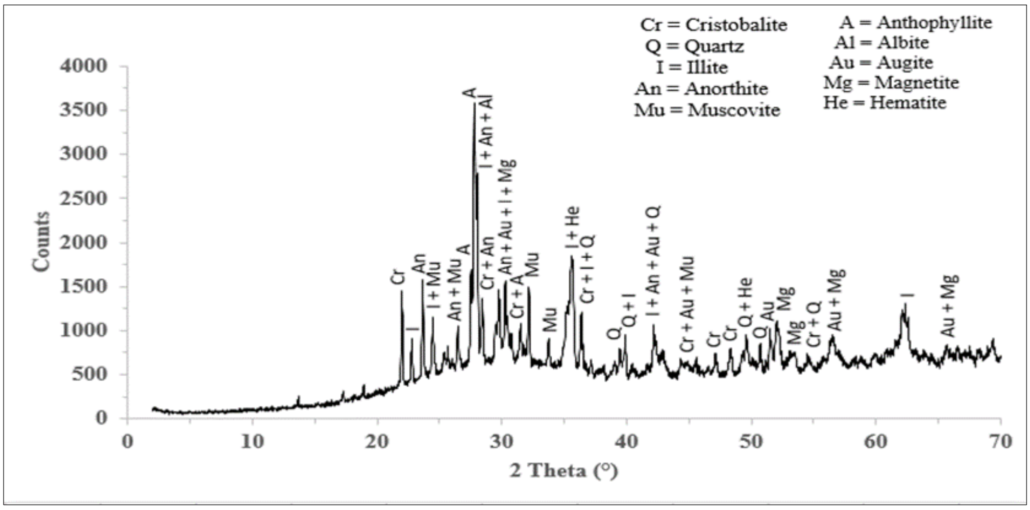

Figure 5 X-ray diffractogram of natural pozzolan

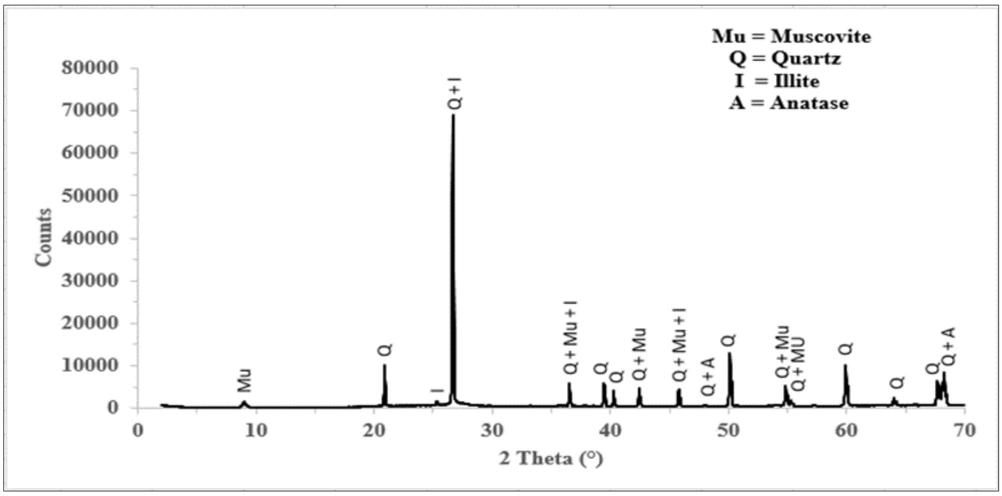

Figure 6 Artificial pozzolan x-ray diffractogram (TAC)

The sand used is of a siliceous nature with rounded grains of size less than 2 mm from the Sanaga river in the district of Ebepda, Lékié department, central region of Cameroon. Before its use, a granular correction was carried out on this sand by washing, drying and sieving the raw material in order to have a continuous granulometry in accordance with the standard sand spindle prescribed by the EN 196-1 Standard. The particle size analysis of this sand was made through a sieve column of the BS 410-1986 standard (2; 1.6; 0.5, 0.16; 0.080) and an Endecoutts EFL 2000 electric sieve. The physical properties of this sand are presented in table 2.

Table 2 Physical properties of the sand used

Physical properties	**Fineness modulus**	**Uniformity coefficient**	**Curvature coefficient**	**Sand equivalent (%)**	**Specific weight (kN/m^3)**
Values	2.64	6.32	1.45	90.04	2.65

2.2. Experimental procedure

2.2.1. Design of binder and preparation of test specimens

Ternary cement pastes were obtained by stirring mixtures of solid powders of Portland cement substituted by natural or artificial pozzolan at percentages of 10, 20, 30 and 40% (Table 3) with the water for 5 minutes. The liquid/solid ratio that permitted a good workability of the paste was 0.305. Mortar was obtained by stirring mixtures of solid elements of ternary cement in various proportion and sand (Table 4) with the water for 5minutes. The liquid/solid ratio that permitted a good workability of the mortar was 0.125. After homogenization, the fresh pastes and mortar were molded in cylindrical molds of 20 cm diameter and 40 cm height.

The molds were vibrated slightly to eliminate air bubbles in the paste and the mortar then left to cure for 24 hours in the mold at ambient temperature of 24±2°C. Thereafter hardened samples were removed from the molds and kept in open air in the laboratory for further tests.

Table 3 Dosing of mixtures for cement pastes

Sample codes	**Mixtures (g)**		
	CPA	**NP/AP**	**Water**
CPA	300	0	91.5
10%P	270	30	
20%P	240	60	
30%P	210	90	
40%P	180	120	

Table 4 Dosage of mixtures for standardized mortars

Sample codes	**Mixtures (g)**			
	CPA	**NP/AP**	**Water**	**Sand**
CPA	450	0	225	1350
10%P	405	45		
20%P	360	90		
30%P	315	135		
40%P	270	180		

2.2.2. Tests on fresh paste and hardened mortar

The initial setting time according to ASTM C 191-13 in which the test was performed to the fresh pastes using a standard Vicat hand-operated apparatus equipped with a 1.13 mm diameter needle [22]. Linear shrinkage (S_L), water absorption (WA), apparent density flexural and compressive strength tests were done on hardened mortar samples at 7 and/or 28 days. Linear shrinkage was calculated using formula (1) after taking the measurements on the test specimens with a digital caliper. L_o was the initial length of the test specimen and L its length at the selected curing duration.

$$\boldsymbol{S_L} = \frac{\boldsymbol{L_0 - L}}{\boldsymbol{L_0}} \text{ x } 100 \text{ ....(1)}$$

The water absorption (WA) of test specimens was done on the basis of ASTM C642-13[23]. Calculations were done using formula (2), where Mh was the weight in grams of the specimen after immersion in water for 48 hours and Ms its weight after drying the specimen at 105°C for 48 hours.

$$WA(\%) = \frac{Mh - Ms}{Ms} \times 100 \text{ .... (2)}$$

The apparent density of test specimens was determined by dividing their dry weight by their volume.

The flexural strength is carried out on the bending apparatus by placing the specimen symmetrical and centered on the plate then a continuous load is applied to the specimen at a speed of 0.001 MPa / s until failure and the test is carried out by the load reading. The compressive load in Newton of test specimens was obtained using an electro-hydraulic press (Instron 1195 compression machine) under continuous and progressive loading at a speed of 3 mm/min. until rupture. The compressive strength was calculated by dividing the measured load of test specimens by their surface.

3. Results and discussions

3.1. Initial and final setting time

The variation of the initial and final setting time of the pastes as a function of the rate of substitution of the cement by different pozzolans is illustrated in Fig. 7. They represent the start time of setting of each paste of the cement samples observed from their Start time of mixing. This time reflects the moment beyond which the hydration reaction accelerates, leading to a stiffness of the paste which would prevent molding of the material. It is related to the extent of the hydration reaction in the mortar [22]. At this time, the amount of setting regulator contained in the cement is consumed by the reaction. It appeared that the initial and final setting time increased with the addition of pozzolans (natural or artificial) in the paste compared to those containing no additions. Y. Tchedele Langollo and al., [24] made the same observation when they substituted cement with grinding glasses. Thus for a partial substitution of CPA of the order of 0 to 40% by pozzolan, the initial and final setting time varied respectively from 124 to 208 min and 181 to 254 min for PN then from 124 to 196 min and 181 at 196 min for the BP which confirms that at a young age, the setting is faster for the CPA paste because the influence of the pozzolan had the effect of delaying the hydration of the cement. This retardation effect can be attributed to the decreasing cement content with the auxiliaries.

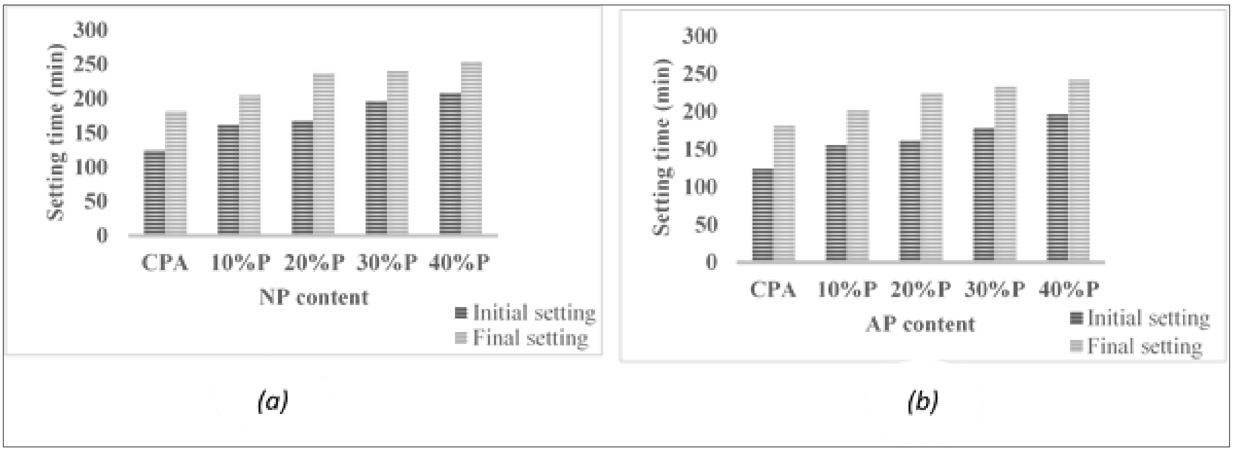

Figure 7 Initial and final setting time with addition of PN (a) and PA (b)

A comparative study has shown us that for the start of setting, paste based on 10%, 20%, 30% and 40% of natural pozzolan show an increase of 4.32%, 4.17%, 9.18% and 5.77% respectively compared to the cement pastes containing artificial pozzolan and at the end of setting, we noticed that the pastes based on 10%, 20%, 30% and 40% of natural pozzolan showed an increase of 1, 96%, 5.49%, 2.92% and 5.72% respectively as compared to cement pastes containing artificial pozzolan which may be due to the absorption of additions and the fineness of the resulting cements which may influence the setting results, since the more absorption is the materials, the longer is the setting time. These times correlate with the consistency of each sample of cement because the higher the consistency, the greater the time to start setting. From the point of view of the setting start time, all these cements comply with standards NF EN 196-3 and NC 235: 2005 - 06 which require this time to be greater than 60 min.

3.2. Linear shrinkage

The linear shrinkage after 28 days of hardening of the mortars as a function of the proportions of each type of pozzolan is shown in Fig. 8. A slight shrinkage of the test pieces is observed during hardening and drying. At 28 days of hardening, this shrinkage was less than 0.2% in all the samples, which complies with standard NF P15-433. For the elaborate specimens, there was an increase in shrinkage as the pozzolan level increased. This can be explained by the decrease in the number and diameter of the pores of the hydrated cement paste, as well as the formation of a secondary CSH. The specimens with artificial pozzolan were more affected by drying shrinkage due to the higher specific surface area of TAC compared to NP. For the specimens containing 10 and 20% pozzolan, the shrinkage was almost similar, showing the balance of the C / E ratio.

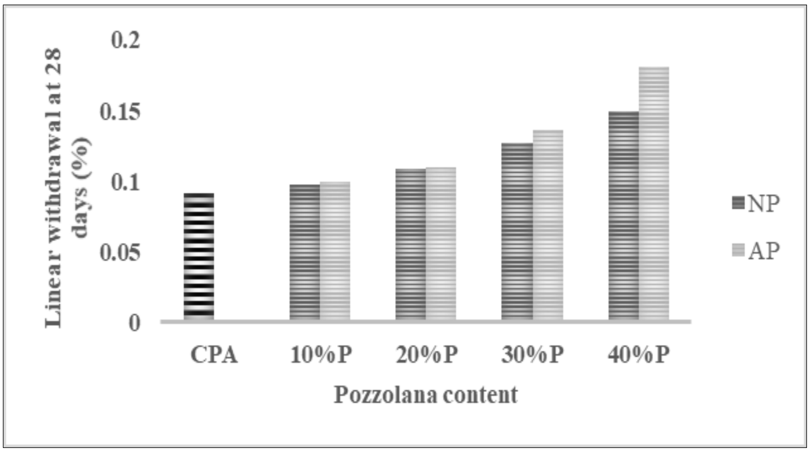

Figure 8 Linear shrinkage of test pieces at 28 days

3.3. Water absorption

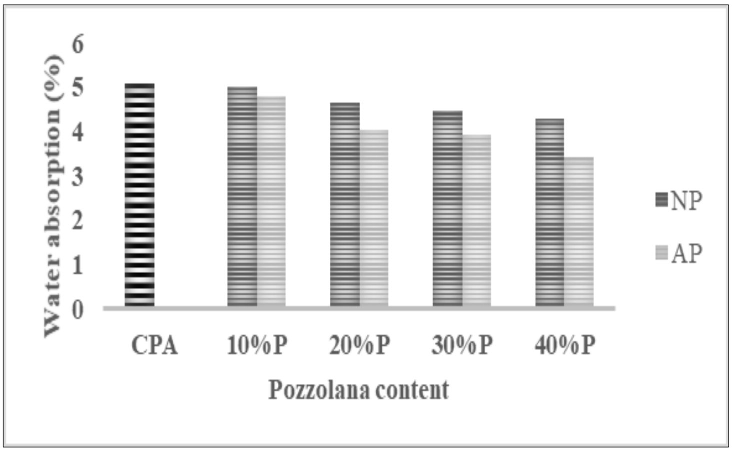

Figure 9 Water absorption of mortars

The capillary absorption rate is significantly influenced by the combination of binder used [25]. It plays an important role in the durability of materials. Fig. 9 shows the water absorption rate of the test pieces which decreases when the percentage of pozzolan increases in the mortars. This finding is in agreement with the observations made by W. Deboucha and al., who showed respectively that the water absorption coefficient of the capillary mortar is improved thanks to the use of 40% of natural pozzolan as a replacement for cement. And absorption values decrease with increasing metakaolin content in mortar [25, 26]. This reduction in absorption is due to the greater fineness of the various additions compared to cement [27]. 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 adjuvants. The results also reveal that AP improves the rate of water absorption relative to NP due to its specific surface area which is greater than that of NP. We record an absorption rate of 5%, 4, 65%, 4.46% and 4.29% at different percentages of substitution by NP and 4.81%, 4.03%, 3.92%, and 3.42% for the same percentages of substitution by AP, ie an improvement of 3.81%, 13.26%, 12.08% and 20% respectively. This improvement is justified by the specific surface area of the AP which is greater than that of the PN. Some studies have shown that the rate of absorption may decrease with time to cure. This could be explained by the densification of the microstructure due to the hydration process [28].

3.4. Apparent density

Density is the amount of material packed in a given space. Fig. 10 shows the bulk density of the mortars after 28 days of curing. This property has decreased with the substitution rate of pozzolans. The trend is consistent with the water absorption results. The particles of NP and AP are less dense, compared to CPA (2.872 g / cm3 for PN, 2.724 g / cm3 for AP and 3.14 g / cm3 for CPA) because they changed the compactness of the mixtures and contributed to reduce the bulk density of the hardened mortar. The mortar containing 10% of PN has an apparent density very close to that of the mortar with CPA, so their longer term behavior will be necessary for a good comparison. PN compared to AP provides better results. The smallest value of the densities is 2172 kg / m3 obtained at 40% substitution by the PA which is compatible with the results obtained in compression.

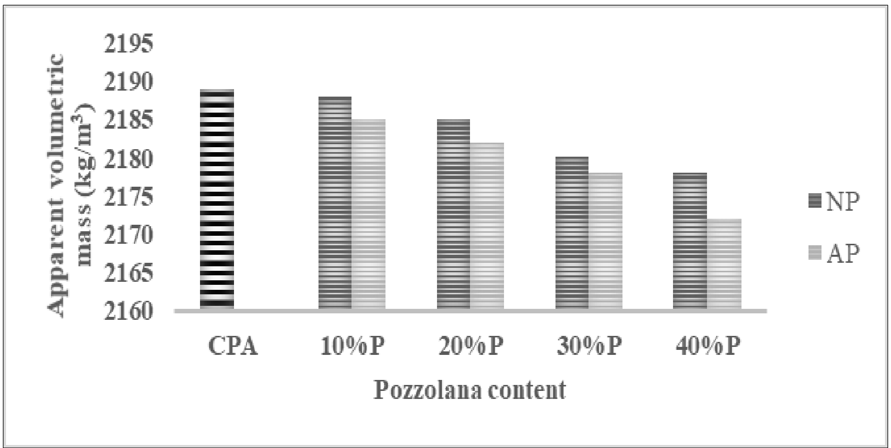

Figure 10 Apparent density of mortars at 28 days

3.5. Flexural strength

Fig. 11 shows the effect of pozzolans on the flexural strength of mortars at different ages, namely 7 (Fig. 11a) and 28 days (Fig. 11b). We observe systematic reductions in the resistance of mortars at different ages as the percentage of pozzolan increases. It is observed that the rate of reduction in resistance of mortars with the addition of pozzolan compared to mortar with CPA tends to decrease considerably at young age and tends to increase on the 28th day. This reduction for NP and AP goes from 12.25% to 46.75% and 14.01% to 39.81% at a young age, then from 4.17% to 30.42% and 5.28% at a young age, respectively. 39.67% 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 physico-chemical effect of the different mixtures [29]. Fig. 11 also shows that the mortars with NP and AP have almost the same strengths for a substitution rate of 10%. At 20 and 30% substitution, the mortar with NP offers better resistance compared to the mortar with AP at all ages but at 40%, we observe a dominance of the mortar with AP at 7 days and a reverse trend at 28 days. This variation in resistance between mortars with the addition of pozzolanic materials does not reach 5% at young age but at 28 days, it is 10.9%, 13.41% and 13.30% for 20%, 30% and 40 % of substitution. A similar phenomenon was observed by M. Benkaddour and al., 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 age, which leads to less intense hydration at young ages by inducing low resistance (setting retarder effect) [30]. So comparatively between the two pozzolans we can say that under flexion criterion, the pozzolanic activity of the NP is more interesting compared to that of the AP.

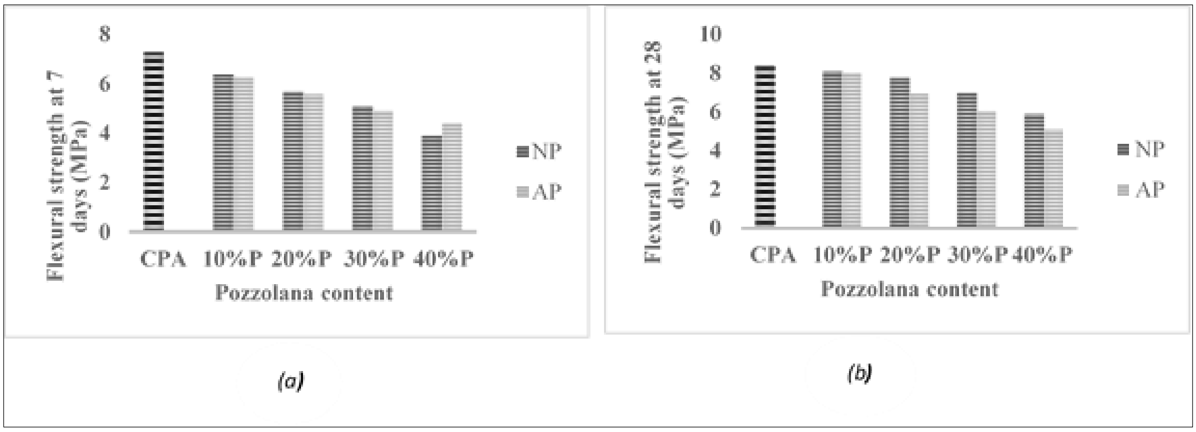

Figure 11 Flexural strength at 7 days (a) and 28 days (b)

3.6. Compressive strength

Figure 12 illustrates the development of compressive strengths for the different mortars with different percentage of cement substitution by pozzolans at 7 and 28 days. The compressive strength increases over time for all mortars but decreases with increasing pozzolan content, which is identical to what is observed in the literature [25, 26, 31]. 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 formed [32]. The mortar without addition after 7 and 28 days of curing offers a compressive strength of 32.45 and 50.93 MPa respectively. These resistances are superior to all the resistances of the mortars with pozzolanic addition except that of the mortar with 10% of PN at 28 days which offers a very close resistance. This observation is similar to that of [33, 34], who obtained a resistance to 10% substitution by Metakaolin greater than that of the mortar containing 0% Metakaolin [33, 34]. The drop in resistance may be due to the fineness of the pozzolans used which are greater than that of the substituted CPA because M. Cyr et al, have shown that the more the fineness of an addition increases the more the physical effect of its grains takes advantage of the hydration process where hydrates take the particles of the addition as a nucleation site which catalyzes the hydration of the cement grains [35].

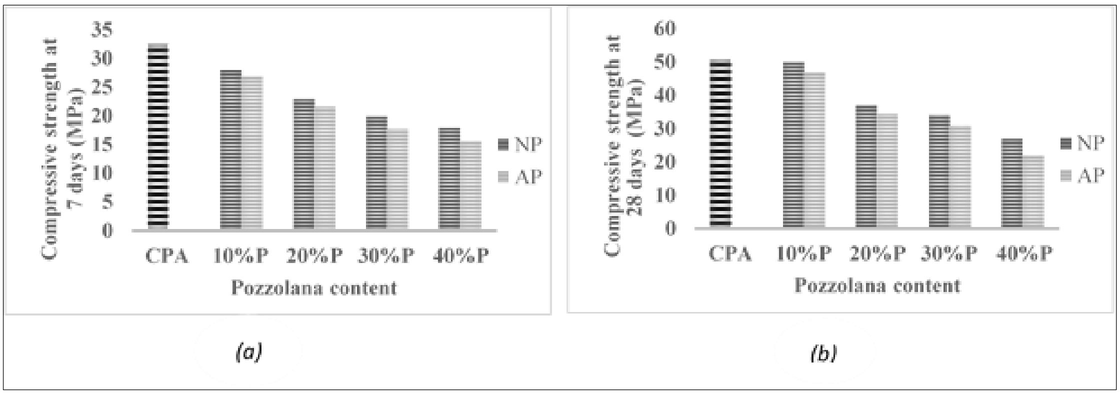

Figure 12 Compressive strength at 7 days (a) and 28 days (b)

Mortars with substitution of CPA by PN offer better resistance at different proportions and at all ages compared to mortar made of PA. The mortar with 40% of PA has a resistance of 15.57 MPa at 7 days and 21.93 MPa at 28 days and at 30% of PA we have a resistance of 30.89 MPa at 28 days while that with 40% of PN to a resistance of 26.94 MPa at 28 days. This drop in strength for mortars containing 40% PN and 30-40% PA can be attributed to the insufficient amount of lime released during the hydration of the cement and consequently to incomplete chemical reactions. Under the compressive strength criterion, and in accordance with standard NF P 15 301, it can be said that cements containing 30% and 40% of PA and 40% of PN do not meet the classification criteria, then for a normal substitution, we should limit ourselves to 30% for the PN and 20% for the BP. However, for 10% of pozzolans, strengths greater than 42.5 MPa at 28 days are recorded, which could be considered as a Portland cement of class 42.5. This explains the fact that this percentage can contribute to the kinetics of hydration hence the existence of two types of calcium silicate (CSH) in cement-based systems with additives [36] whose density can have a significant effect on the mechanical properties of the mortar [37]. The properties of the latter can affect the macroscopic behavior of mortar and concrete. However, up to 30% PN and 20% PA, a resistance greater than 32.5 MPa at 28 days is recorded, which allows them to be attributed to the 32.5 class.

4. Conclusion

The comparative study of the effect of a natural pozzolan and an artificial pozzolan on the hydraulic properties of Portland cement mortar has been investigated, and the results obtained reveal that the presence of pozzolans in the cement is favorable to the formation of gels.

- The diffractograms reveal the presence of a considerable quantity of the vitreous phases in the natural pozzolan and that this natural pozzolan plays a filling role in the cement matrix. Pozzolans played the role of retarded setting in the mixtures.
- The natural pozzolan delays setting more as compared to the artificial pozzolan.
- The water absorption of the test pieces and the bulk density decreased as the percentage of pozzolans increased. Their presence contributed to the fall of resistance.
- The presence of natural pozzolan in CPA offers better results as compared to artificial pozzolan.
- Pozzolanic additions of up to 30% for natural pozzolan and 20% for artificial pozzolan can be used in Portland cement, with a beneficial effect on water absorption and setting.
- Pozzolan and thermally activated kaolinite clay are suitable for partial substitution of Portland cement.
- The compressive strength of mortars with natural and artificial pozzolans at 28 days (34.06 MPa and 34.44 MPa), although it is lower than that with 0% addition tested (50.94 MPa) and remains in a regulatory interval, therefore it can be assigned to class 32.5. However, finer grinding of the raw materials and a higher calcination temperature of the clay could provide better results.

Compliance with ethical standards

Acknowledgments

All of the authors would like to express special thanks to MIPROMALO¸ Yaoundé, Cameroon for the experimental results.

Disclosure of conflict of interest

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version. Additionally, there are no conflicts of interest in connection with this paper, and the material described is not under publication or consideration for publication elsewhere.

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