Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 16(5): 2372-2383, October 2022

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Implementation of pozzolanic cement based on activated natural clay (eco-cement): technical challenges and normative aspect

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Received: 03-08-2022 Accepted: 17-10-2022 Published: 31-10-2022

ABSTRACT

Currently, portland cement is the reference in cement; moreover, it has the advantage to be model. However, obtaining the characteristics required for cement imperatively requires the adoption and optimization of its formulation to the requirements appropriated to the word and its environment. The aim of this work was to develop and optimize a composition of a pozzolanic cement (eco-cement) using active additives (activated clay TIT_1) in variable proportion. It will be a question of studying the characteristics of the various cements formulated as well as their implementation, in order to lead to some improvements concerning : the economy, the chemical, physico-chemical properties and the mechanical behavior.

Keywords: Portland cement, optimization, pozzolanic cement, improvement, properties.

INTRODUCTION

Cement is an indispensable (essential) element in the development of a country. Indeed, it contributes to the resolution of housing problems and the realization of infrastructures. Portland cement is obtained by calcining at a very high temperature (about 1450 °C) of the raw material composed of calcareous and clayey rocks. This process, called clinkerization, generates a high-energy consumption (various fossil fuels are used: coal, natural gas, fuel oil, etc.) and very significant CO_2 emissions. According to a study published in June 2009 by the WBCSD (2009), the average global amount of CO_2 emitted per ton of clinker produced in 2006 was 866 kg CO_2/t.

In the current context of sustainable development, the protection of the environment has become one of the major concerns of society, and the development of eco-cements is a real challenge for the cement industry. These eco-cements will have to respect the standards applied to the current

DOI: https://dx.doi.org/10.4314/ijbcs.v16i5.43

cements, to have characteristics similar to that of the current cements and having less impact on the environment.

One of the alternative solutions is to partially substitute the Portland cement clinker with pozzolanic additions in order to preserve or improve the performance of the cement. These additions, which are mineral additions, must have a certain chemical activity called "pozzolanic". They are composed mainly of silica and alumina reactivate that react with the portlandite, resulting from the hydration of the clinker, which improves the performance of the cement. Cements, whose main constituent is clinker, may contain other mineral elements, in the form of additions to clinker with or without pozzolanic or hydraulic properties. Hydraulic properties mean that the material has the ability to harden and to make takes in the presence of water. The pozzolanic properties mean that the material can be combined in the presence of water with portlandite (lime) at ambient temperature and give it hydraulic qualities.

The materials presenting some pozzolanic properties enter, in variable proportions (as main constituents or additives) in the composition of different categories of cements:

- portland Composite Cements (CPJ) with portland cement clinker content greater than or equal to 65% (Portland composite cements as such or Portland cements with pozzolan);

- pozzolanic cements (having satisfied the pozzolanicity test defined by standards NF EN 197-1 (2013), ASTM-C-618 (2012) and NF EN 196-5 (2013), in which the content of materials pozzolanic character is between 30 and 40% ;

- composite cements, including notably slag cements and pozzolan (content of these two constituents greater than 35%).

These pozzolanic materials, when they replace a part of the clinker, act on the properties of the material (cement) in the fresh state and in the hardened state. Indeed, they modify the hydration process of the cement, the nature and the structure of the hydrated products. Their incorporation thus acts on the workability, porosity, permeability, diffusivity and mechanical strength of cementitious materials (Ralaï N. 2008)

So the objective of the present work was to formulate a variety of composed cement to basis of the activated thermally natural clay (TIT_1), specifically it is about the determination of the optimal rate of the clay activated to use to put an eco-cement in place (pozzolanic cement).

MATERIALS AND METHODS

Materials

Calcined clay TIT_1

To conduct this study, we chose a local clay from Burkina Faso that we referenced TIT. The characteristics of the clay were previously determined; the clay was calcined at 680 °C for 2 hours to fully benefit from its pozzolanic activity. The material resulting from the calcination has been referenced TIT_1.

Clinker

The clinker used comes from CIMTOGO cement plant in Togo. It was received in non-pulverulent form. It was milled in the laboratory using a ball mill until a Blaine surface of 5200 cm^2/g was obtained.

Gypsum

It is a black rock. The gypsum was used to react in the solution with the clinker in order to prevent a quick setting of the cement.

Cement portland CEM II 32.5 R

The cement CEM II 32.5 R used is a commercial nuance normalized coming from a cement factory of the place. This nuance contains gypsum permitting to control its hold.

The sand

We used for the confection of the mortars of the natural sand. It is about the flinty natural sand. Its grains are of generally isometric and rounded shape.

The wastage water

The wastage water used in this work is drinking water which corresponds to the requirements of standard NF EN 196-1 (2006).

Methods

Preparation of pozzolanic cement

We have elaborated some cements to basis of the clinker ground with additions of 5% gypsum and activated natural clay in proportions of 20%, 30%, and 40% of clinker mass.

All materials (clinker, gypsum, thermally treated clay) have been grinded separately, in a ball mill with a capacity of 5 kg. They were subsequently homogenized and mixed (still in the mill) in the proportions summarized according to a coding system in order to manufacture three (3) types of cement. This type of grinding thus made it possible to control the initial fineness of each of the constituents introduced to manufacture the cement.

The coding system is as follows:

-CP20: cement composed of 75% clinker + 20% pozzolan + 5% gypsum;

-CP30: cement composed of 65% clinker + 30% pozzolan + 5% gypsum;

-CP40: cement composed of 55% clinker + 40% pozzolana + 5% gypsum.

The studied combinations consist of a ternary mixture of clinker, gypsum and pozzolana (noted C, G, and P respectively for clinker, gypsum and pozzolan). The proportions of the constituents are expressed as a percentage by weight relative to the solid mass of the clinker. The mixtures are packaged in polyethylene sachets each containing 450 g.

Combinations with a low mass fraction of pozzolan (< 20%) are intentionally discarded. These combinations are characterized by low clinker substitution.

The dosage of natural gypsum was kept constant (5%), for two reasons: to regulate the setting and not to mask the influence of the addition on the mechanical and chemical properties of the cement. In more we decided not to use any adjuvant in order to avoid all chemical interaction risk.

Preparation of the sand

Before its use, we did a granular correction of this sand in order to have a continuous granulometric in accordance with the spindle of the sand normalized. It is cleaned, dried and prepared to the laboratory while guaranteeing a regularity of its granulometric. The sand is conditioned in sachets of containing polyethylene each 1350 g.

Composition of the mortar

Every mortar is composed in mass of one part of cement and 3 parts of sand. The water of wastage used in this research comes from the faucet exempt of impurities (it is about a drinking water) and whose temperature is of 20 ± 1°C, its quality is in conformity with the prescriptions of standard NF P 18-404 (1960). The mortars have been achieved with the help of a mixer of HOBART mark containing a five liters tank answering the characteristics of standard NF P 15-411 (2006).

The mixing procedure is the one recommended in the standard NF P 15-403 (2006). This standard governs the preparation of the mortar masses prepared in a global zone mixer of 5 liters of capacity, with 2 times of wastage to different speed.

The quantity of water has been adjusted to have the same consistence to know the normal consistence. No superplastifiant has been used for all mortars in order to avoid all chemical interaction risk.

We used normal mortars, according to standard NF P 15-403 (2006) whose composition is the following (Table 1):

The test-tubes of tests have been prepared in accordance with standard NF EN 197-1 (2013) in molds prismatic 40 x 40 x 160 mm^3. They are mechanically compacted in two layers with the help of a table to shocks of 60 strokes to 15 mm of fall height. Leveled once, the molds containing the test-tubes are kept in the environment of laboratory under a temperature of 20 °C ± 1°C and a relative humidity of about 55 ± 5%. The unmolding is done after a length of 24 hours and after the unmolding, the test-tubes have been kept in water in 20 °C ±1°C, until the day of the deadline. These prismatic test-tubes (40 x 40 x 160 mm^3) have been prepared for every mixture and are destined to the mechanical tests.

Analyzes

Physical analyzes

The density of the cements has been determined according to standard NF P 94-054 (1991).

The surface specific Blaine of the cements has been determined according to standard NF EN 196-6 (2012).

The tests of normal consistence or "Vicats consistence" have been achieved according to standard NF EN 196 -3 (2012).

The expansion to hot of our different variants of cements has been determined according to standard NF EN 196-3 (2012).

The beginning and the end of hold of the cements have been determined according to standard NF EN 196-3 (2012).

Chemical analyses

The chemical composition of the different cements formulated as well as the one of the cement witness is determined according to the standard NF P 15-467 (2006) with the help of the fluorescence of the X rays.

The content in equivalent alkalis of our different variants of cements has been determined according to the standard NF EN 196-21 (2014).

Mechanic analyze

The mechanical tests of compression have been carried out on test-tubes prismatic 4x4x16 cm^3. These mechanical tests were carried out at 7, 14 and 28 days of hardening on mortars of cements.

Table 1: Mortars composition.

	Formuled Cement: (450 g)				CEM II 32.5 R (g)	Sand (g)	water (ml)	E/L
Mixture	**Code**	**Clinker (%)**	**TIT_1 (%)**	**Gypsun (%)**	-	-	-	-
M20	CP20	75	20	5	-	1350	270	0.6
M30	CP30	65	30	5	-	1350	280	0.62
M40	CP40	55	40	5	-	1350	290	0.64
MT	-	-	-	-	450	1350	240	0.53

RESULTS

Chemical and physico-chemical characteristics of TIT_1

The physico-chemical characteristics of TIT1 are given in Table 2.

A resistance activity index of 81% can be read, with an amount of amorphous material of 70.5% and a fineness of blaine of 5300 cm^2/g.

The results of the elemental analysis of TIT_1 are given in Table 3.

With regard of the results of the elementary chemical analysis given to the Table 3, the sum % SiO_2 +% Al_2O_3 +% Fe_2O_3 is equal to 90,34% for the TIT_1 material. In addition, the difference between the crude contents of silica and lime (Silica - Lime) which gives the quantity of vitreous phase present in the TIT_1 material is: (56.74 – 0.26) % = 56.48%.

Chemical, physico-chemical and mineralogical characteristics of the clinker

The grinding of clinker got used with the help of a grinder to cannonballs as far as getting a surface of Blaine of 5200 cm^2/g. Its chemical analysis, gotten by Fluorescence of the X-rays, and its mineralogical composition is represented in the Table 4:

In view of these results (Table 4), it can be said that the chemical composition of Togo clinker complies with the French standard NF P 15-317 (2006) according to which: $SO_3 \leq 3\%$; $MgO \leq 4\%$ $Na_2O < 0.5\%$; $K_2O < 1\%$. The equivalent alkali (% Na_2Oeq = Na_2O + 0.658 x % K_2O) is 0.14. In addition, its composition complies with literature data for the majority oxides. The CaO/SiO_2 ratio = 3.2 is greater than 2 required by standard NF EN 196-2 (2006).

Apart from a few percentages, the mineralogical composition of the clinker used for our formulations is in conformity with standard NF P 15-317 (2006). This mineralogical composition reveals that the clinker to be used contains lime and silica in appreciable percentages.

Physico-chemical characteristics of gypsum

The physical characteristics of the gypsum powder are presented in the Table 5.

The value of the blaine specific surface of the gypsum is 8616 cm^2/g.

Granulometric composition of sand

The particle size composition of the sand used was determined by sieving, complies with the requirements of standard NF EN 196-1 (2006). The cumulative refusal percentages obtained by sieving the sand are given in Table 6.

The sand used gave cumulative refusals at the 2 mm sieve a zero percentage (0%).

Characteristics chemical of formulated cements

The results obtained from the chemical analyzes of the cements are reported in the following Table 7:

Looking at the Table 7, we note that all the samples are based on the SiO_2, Al_2O_3, CaO and Fe_2O_3 system but their contents vary according to the addition. We also note, the predominance of calcite in the from (CaO), silica in the from oxide (SiO_2) and alumina (Al_2O_3).

The content of the elements varies considerably depending on the material, and depends directly on the nature of the addition. For these formulated cements, the rate of bound lime (CaO) decreases with the rate of incorporated TIT_1 material. The free lime content of these formulated cements is less than 2%. The content of silicon oxide (SiO_2) in formulated cements increases with the rate of incorporated TIT_1 material. In addition, the sum of the %CaO +%SiO_2 oxides is greater than 50%.

Concerning the rate of alumina in formulated cements, there is also an increase in the rate of Al_2O_3 with the rate of the TIT_1 material. It should be noted that the alumina content in these formulated cements is high compared to that of the control cement. Similarly, the iron oxide content in formulated cements increases with the rate of the substituted TIT_1 material.

Physical characteristics of different cements formulated

The results Physical characteristics of different cement variants are shown in the Table 8.

With regard to the Table 8, all the density values of the various formulated cements are within the range of the prescribed values namely the french standard NF P 94-054 (1991) which describes a value of the density (ρ (g/cm^3)) of cement which is between 2.8 and 3.2 g/cm^3.

Concerning the specific surface blaine (SSB (cm^2/g)) of the cements formulated We also note an increase of the sharpness with the rate of the TIT_1 material.

The water / cement (W/C) ratio of the formulated cements is higher than that of the control cement. This ratio increases with the content of the substituted TIT_1 material.

The hot expansion of different cement variants is regular and it is 0.5 mm for these formulated cements.

Alkali content

The equivalent alkali content of our different cement variants has been determined and is presented in the Table 9.

The equivalent alkali contents in the formulated cements are well below 0.6%.

Cement setting time

The results of the beginning and the end of hold of the cements are represented in the Figure 1:

In view of the results, it is noted that the start and end of setting times of the cements are strongly influenced by the addition of the TIT_1 material. It can be seen that the start of setting times However, there is an addition threshold beyond which these times decrease. We also note that the start and end of setting times of the cements are greater than 75 minutes

The setting time, which is the difference between the end and start of setting times, increases with the addition of TIT_1 material.

Mechanical characteristics of the mortars of the cements formulated

The results of the mechanical compression tests carried out on cement mortars with different formulations are represented in the Figure 2:

The analysis of the different histograms (Figure 2) makes it possible to make the following comments:

- the compressive strengths of mortars incorporating additives typically evolve like the control portland cement MT (CEM II 32.5 R) during hydration;
- the strengths of all mortars increase steadily with age and show no decrease;
- each of the cementitious additions, however, modifies the evolution of mortar resistance in a specific way. Overall, the substitution of the clinker by the TIT_1 material leads to an increase in the compressive strengths;
- at first age (7 days), TIT_1 material binders have developed compressive strength greater than 16 MPa, threshold required by standard NF EN 196-1 (2006), except M40;
- the compressive strength at 28 days increases considerably with the increase in the percentage of addition up to 30%, after which a decrease in compressive strength is observed;
- the 28-day compressive strength of formulated cements is greater than 32 MPa in accordance with standard NF EN 196-1(2006) required for CEM II 32.5 portland cements.

These results suggest that TIT_1 material has a positive effect on the development of compressive strength.

Table 2: Some physico-chemical parameters of TIT_1.

	Density [g/cm^3]	Blaine Fineness [cm^2/g]	% amorphous	% CaO fixed		Resistance activity Index (%)
				1 day	28 days	
TIT_1	2.92	5300	70.5	58	90	81

Source: Ganon et al. (2015).

Table 3: Chemical composition of TIT_1.

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	PF_{1000}	Total
% mass	56.74	22.71	10.89	0.26	0.78	0.16	0.26	2.57	91.8

PF_{1000}: loss to fire in 1000 °C

Table 4: Compositions chemical and mineralogical of the clinker.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	CaO_{Libre}	Total
Clin-ker	21.17	5.90	3.90	67.08	1.09	0.19	0.12	0.06	1.98	99.51
Refe-rence	18-24	4-8	1-8	60-69	< 5	< 3	< 2	< 2	-	-

Mineralogical composition

	C_3S	C_2S	C_3A	C_4AF
Clin-ker	66.89	10.59	9.00	11.86
Refe-rence	50 – 65	15 – 20	8 – 10	7 – 10

Table 5: Physico-chemical characteristics of gypsum.

Caractéristiques	Values
Density mass (g/cm^3)	2.64
Blaine specific surface (cm^2/g)	8616

Table 6: Particle size composition by sieving the sand.

Opening of the sieve meshes (mm)	Accumulative refusal (%)
0.08	99 ± 1
0.16	87 ± 5
0.50	67 ± 5
1.00	33 ± 5
1.60	7 ± 5
2.00	0

Table 7: Chemical compositions of the various cements formulated.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	Na_2O	CaO_{Free}	Total
CP20	27.37	12.65	4.91	49.94	1.02	0.27	0.11	0.09	1.37	96.36
CP30	30.24	16.61	5.74	41.27	1.02	0.25	0.09	0.11	1.32	95.33
CP40	33.09	20.36	7.47	30.11	0.98	0.27	0.08	0.11	1.51	92.47
CEM II 32.5 R	29.95	8.38	4.35	43.72	2.94	2.46	0.53	0.55	1.82	92.88

Table 8: Physical characteristics of different cement variants.

Variant	ρ (g/cm^3)	SSB (cm^2/g)	W/C for normal consistency	Expansion (mm)
CP20	2.89	7400	0.34	0.50
CP30	2.89	8600	0.38	0.50
CP40	2.85	9300	0.39	0.50
CEM II 32.5 R	2.92	3700	0.32	1.00

Table 9: Results of the percentage of equivalent alkalis of the different cement variants.

Variant	Alkalis equivalent (%)
CP20	0.16
CP30	0.17
CP40	0.16
CEM II 32.5 R	0.90

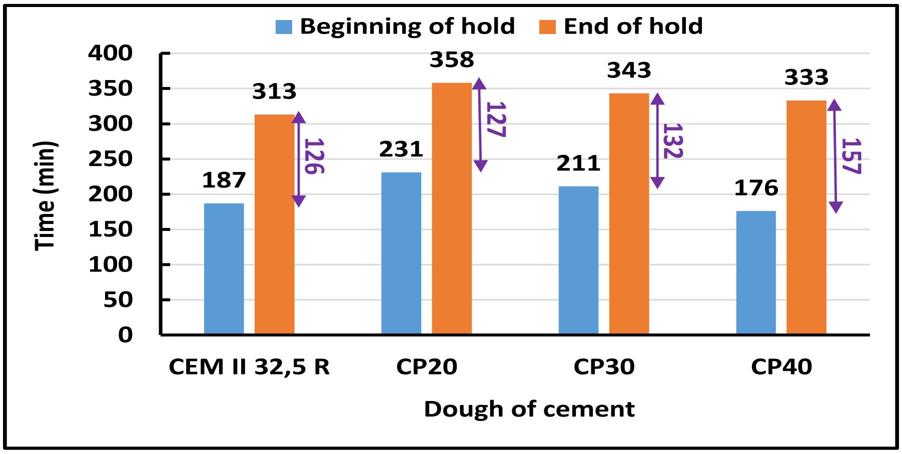

Figure 1: Setting time of different cement variants.

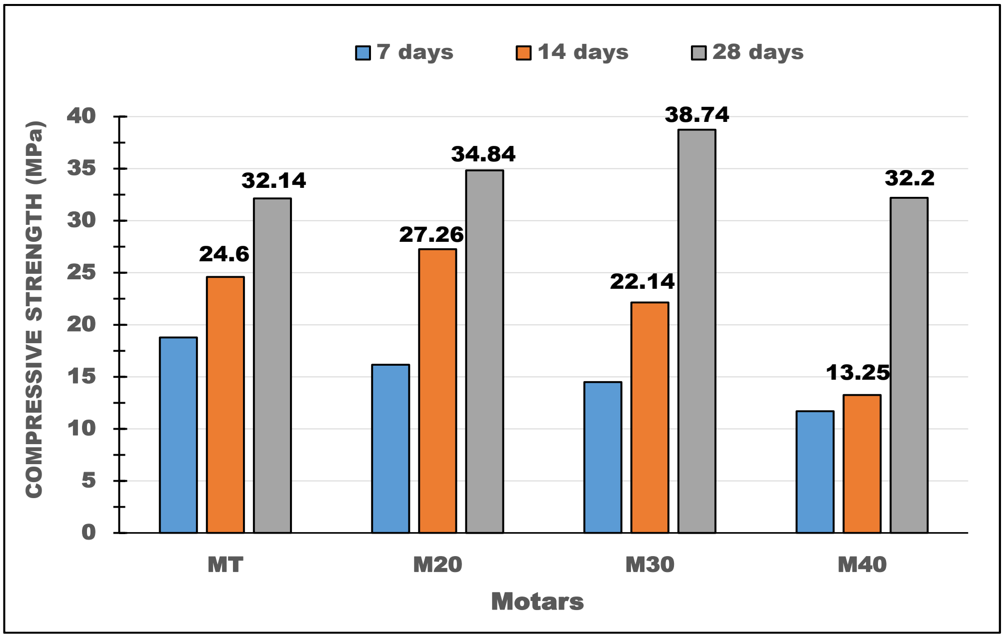

Figure 2: Results of mechanical compressive strength tests of mortars of different cement variants.

DISCUSSION

Regarding the chemical analysis of TIT_1, the sum % SiO_2 +% Al_2O_3 +% Fe_2O_3 is equal to 90,34%. This value is greater than 70%, the nominal value given in the standard ASTM C 618 (2012) for pozzolanic materials. In addition, the difference between the crude contents of silica and lime (Silica - Lime) which gives the quantity of vitreous phase present in the TIT_1 material is: (56.74 – 0.26) % = 56.48%, this suggests that the calcined clay has a vitreous phase. The TIT_1 material is then acidic and therefore presents the possibility fixing the portlandite (lime) released by thhnhe cement.

Many studies carried out on pozzolanic materials also suggest that there is a relationship between pozzolanic activity and the quantity of vitreous phase present in the material (Cabrera J. 2000; Rojas M. 2001).

Also the Blaine fineness of TIT_1 is 5300 cm^2/g (Table 2). This value is higher compared to fast-strength cements whose range is between 4000 and 5000 cm^2/g according to standard NF EN 196-6 (2012). This observation suggests that the TIT_1 material is finer and can contribute to the fineness of the cements to be formulated. The study conducted by San Nicolas (2011) showed that the the pouzzolanic material contains more fines than cement.

The results of the elementary chemical analysis and the mineralogical composition of the clinker are in conformity with the data of the literature according to the French standard NF P 15-317. In addition, the equivalent alkali (%Na_2Oeq = Na_2O + 0.658 x %K_2O) is 0.14 and is less than the value 0.6 and reflects a good content of alkalis in the clinker to probably avoid alkali-aggregate reactions.

The C_3A rate in the clinker is 9%. This rate shows that it is a suitable clinker for a sulphate-resistant pozzolanic cement according to standard NF EN 197-1 (2013).

Concerning the chemical compositions of the formulated cements, the results show that the chemical compositions of the formulated cements are typical of a portland cement and comply with standard NF EN 197-1 (2013).

For these formulated cements, the rates of silica (SiO_2) and alumina (Al_2O_3) increase with the rate of incorporated TIT_1 material. On the other hand, a decrease in the rate of bound lime (CaO) is observed. This is due to the dilution effect.

The free lime content of these formulated cements is less than 2%, the value required by standard NF EN 196-2 (2006). This suggests that our formulated cements will resist shrinkage and volume change upon hydration.

The sulphate content of these formulated cements is significantly lower than 3%, the threshold required by standard NF EN 196-2 (2006) for sulphate-resistant pozzolanic cements. This suggests that formulated cements are receptive to grindability. In addition, the sum of the %CaO + %SiO_2 oxides is greater than 50%, the threshold value required by standard NF EN 197-1 (2013).

The specific surface area of formulated cements is quite high. We also note an increase in fineness with the rate of the TIT_1 material. This finding suggests that the TIT_1 material is thinner and contributed to the thinness of the formulated cements. This high fineness of the formulated cements will bring into play their very high reactivity.

The water/cement (W/C) ratio of formulated cements increases with the content of the substituted TIT_1 material. This result is in agreement with the results of the blaine specific surface. The finer the cement, the greater its demand for water. Thus, with the incorporation of very fine TIT_1 material, the demand for water increases to allow the various grains to be wetted. It should also be added the irregular and porous shape of the TIT_1 material which contributes to the increase in the quantity of water. These W/C ratios are very interesting because they are close to the recommended value for having a cement with good durability. Indeed, Aïtcin Pc., in his work “Ecostructures in concrete” clearly shows that the ideal consistency (W/C) for a cement paste is 0.36. This value (W/C= 0.36) ensures complete hydration of the cement paste. For lower values, a possible consistency is observed and can negatively affect performance. Added to this is incomplete hydration. For larger ratios, a quantity of water remains within the cementitious matrix and is a source of fragility.

The hot expansion of the different cement variants is regular and is well below 10 mm, the value required in the literature, namely an expansion of less than 10 mm (≤ 10 mm) according to standard EN 196-3 (2013). This shows a great stability of these formulated cements. This stability is explained by the quantity of free lime which is less than 2%, the value required by standard NF EN 196-2 (2006).

The equivalent alkali contents in formulated cements are significantly lower than 0.6%, the value required by standard NF EN 196-21 (2014). This suggests that these formulated cements will be more chemically stable and with low possibility of alkali-aggregate reactions.

Cement onset times comply with standard NF EN 196-3 (2012) which requires an onset time for CEM 32.5 type cements ≥ 75 minutes. The delay in the onset of setting of the formulated cements compared to the control cement is explained by the increase in their water demand. This extra amount retards setting increases with the addition of TIT_1 material. This result corroborates the onset times of our formulated cements. In addition to the amount of water that has increased, the pozzolanic reaction is slow and does not allow the formation of C-S-H in large quantities at young ages. To this end, the dilution effect due to the contribution of the TIT_1 material is associated. This dilution helps to reduce the amount of C-S-H and influences the setting time. These results are in agreement with the studies carried out by Pan et al. (Pan SC. 2003); Coutand et al. (Coutand M. 2006); Dyer et al. (Dyer T. 2011). This shows that TIT_1 pozzolan has a significant effect on setting times (beginning and end) and therefore on hydration.

Regarding the compressive strength, overall, the substitution of the clinker by the TIT_1 material leads to an increase in the compressive strengths. The compressive strength at 28 days of formulated cements is greater than 32 MPa in accordance with standard NF EN 196-1 required for Portland CEM II 32.5 cements.

The addition of calcined clay led to an increase in the strength of the mortars compared to that of the reference mortar and this at the age of 28 days. The rate of strength development of mortar containing calcined clay depends on the combination of the hydration of the clinker and the pozzolanic activity of the pozzolanic addition. The TIT_1

calcined clay interacted with the cementitious paste:

- either by filler effect where the dimensions of the particles improved the compactness of the mixture and thereby reduced the transport of fluid in the cementitious matrix;

- either by pozzolanic effect by which a siliceous or alumino-siliceous compound has reacted in the presence of water with the portlandite created during the hydration of the clinker to form binding compounds (C-S-H). These pozzolanic additions influenced the pore structure, not only due to the pozzolanic reaction, but also because they were able to infiltrate between the cement grains and serve as nucleation points for the formation of hydrates. This led to a densification of the structure, allowing, among other things, the improvement of the properties of the hardened cement paste, in particular the mechanical resistance.

These results suggest that TIT_1 pozzolan has a positive effect on the development of compressive strength.

Conclusion

The choice of the type of cement and its dosage depend on both the desired performance (mechanical strength, resistance to aggressive agents) and the nature of the other components. The cement dosage is not determined by an absolute theoretical calculation, but it results from the application of rules whose relevance has been appreciated by use and verified experimentally. In addition, the mixing of different cement materials is not a simple operation, because of the incompatibilities that may exist between different constituents. Moreover, the mixture of compatible cementitious materials does not always lead to the same results; possible interactions (or interactivities) can exist between the different types of materials. These interactions can be manifested by synergisms or antagonisms between constituents, which are difficult to detect.

The optimization of the cement formulation is based on several criteria that must be compromised: consistency, strength, durability and economy. The classification of the cements is based on the strengths obtained on standardized mortars. A ternary cement was formulated based on clinker, TIT_1 (pozzolan) and gypsum. The results obtained show that the overall chemical compositions of the cements formulated are typical of a portland cement and comply with standard NF EN 197-1 (2013) standard. The water / cement ratio (W/C) of the formulated cements is close to the recommended value (W/C = 0.36) for a cement of good durability. The setting start times of the formulated cements are in accordance with standard EN 196-3 standard, which requires a setting start time for type 32.5 cements ≥ 75 minutes. Mechanical tests carried out on 4x4x16 cm^3 prismatic specimens showed that the 28-day compressive strength of the formulated cements is greater than 32 MPa in accordance with standard NF EN 196-1 (2006) required for portland cements 32.5. The formulated cements are therefore of the CEM IV 32.5 type.

COMPETING INTERESTS

The authors declare that there is no competing interest.

AUTHORS' CONTRIBUTIONS

All authors have contributed significantly to the realization of this work and to the drafting of the manuscript and have approved it in its current form.

ACKNOWLEDGMENTS

This research was made possible through funds provided by the University Ouaga I Professor Joseph Ki-Zerbo. We express our gratitude to all the staff National Laboratory of Building and Public Works (LNBTP) of Burkina Faso.

REFERENCES

Aitin PC, Mindess S. 2013. *Ecostructures in Concrete*. Eyrolles edition; p.276.

AFNOR, NF EN 196-1. 2006. Methods of testing cement - Part 1: determination of mechanical strength" sagaweb.

AFNOR, NF EN 196-2. 2006. Methods of testing cement - Part 2: Chemical analysis of cements.

AFNOR, NF EN 196-3. 2012. Methods of testing cement - Part 3: Determination of setting time and stability.

AFNOR, NF EN 196-5. 2013. Methods for testing cement - Part 5: Pozzolanicity test for pozzolanic cements.

AFNOR, NF EN 196-6. 2012. Test methods for cements - Determination of fineness. sagaweb.

AFNOR, NF EN 196-21. 2014. Methods of testing cement - Part 21: Determination of chlorine of carbon monoxide and alkalis.

AFNOR, NF EN 197-1. 2013. Cement - Part 1: Composition, specifications and conformity criteria of common cements. sagaweb.

AFNOR, NF P 94-054. 1991. Soils: recognition and tests - Determination of the density of the solid particles of soils – Waterproof method of water.

AFNOR, NF P 15-317. 2006. Hydraulic binders - cements for work at the sea.

AFNOR, NF P 15 – 403. 2006. normal Sand and normal mortar.

AFNOR, NF P 15-411. 1960. Hydraulic binders. Technical testing. Mixer.

AFNOR, NF P 15-467. 2006. Hydraulic binders - Instrumental method of analysis of cements by X-ray fluorescence spectrometry.

AFNOR, NF P 18-404. 1981. Concrete - Essays study, convenience and control - Confection and conservation of the specimens.

ASTM C 618. 2012. Standard Specification for Ash Coal and Raw or Calcined Natural Pozzolan for Use in Concrete.

Cabrera J, Rojas MF. 2001. Mechanism of hydration of metakaolin-lime-water system. *Cement and Concrete Research*, **31**(2): 177-182. DOI: https://doi.org/10.1016/S0008-8846(00)00456-7

Coutand M, Cyr M, Clastres P. 2006. Use of sewage sludge ash as mineral admixture in mortars. Proceedings of the institution of civil engineers. *Construction Materials*, **159**(4): 153–162. DOI: https://doi.org/10.1680/coma.2006.159.4.153

Dyer T, Haliday J, Dhir R. 2011. Hydration chemistry of sewage sludge ash used as a cement component. *Journal of Materials in Civil*, **5**: 648–655. DOI: https://doi.org/10.1061/(ASCE)MT.1943-5533.0000221

Ganon F, Yameogo A, Sorgho B, Zerbo L, Seynou M, Younoussa M, Ouedraogo R. 2015. Preparation of a pozzolana based on a clay raw material from Burkina faso. *Scientific Study & Research Chemistry & Chemical Engineering, Biotechnology, Food*, **16**(4): 371–383. DOI: https://doaj.org/article/77ed92b7484a41aeb74e197bf662e482

Pan SC, Tseng DH, Lee CC, Lee C. 2003. Influence of the fineness of sewage sludge ash on the mortar properties. *Cement and Concrete Research*, **33**(11): 1749–1754. DOI: https://doi.org/10.1016/S0008-8846(03)00165-0

Ralaï N. 2008. cement matrix compounds (reminders and interactions). The materials saga. *Cement, Concrete, Plaster, Lime* Nº 890. Available online: http://doc.lerm.fr/wp-content/uploads/2013/08/matrice-cimentaire-rafai.pdf

Rojas MF, Cabrera J. 2001. Influence of MK on the reaction kinetics in MK/lime and MK-blended cement systems at 20°C. *Cement and Concrete Research*, **31**(4): 519-527. DOI: https://doi.org/10.1016/S0008-8846(00)00465-8

San Nicolas R. 2011. Performance approach to concretes with metakaolins obtained by flash calcination. Thesis, University of Toulouse, France. DOI: https://tel.archives-ouvertes.fr/tel-00756481

WBCSD. 2009: Cement Industry Energy and CO_2 performance "Getting the numbers right". Available online: http://docs.wbcsd.org/ 2009/06/CementIndustryEnergyAndCO2Performance.pdf.