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Article

Laterite Based Low Carbon Binder for Circular Economy in Yaoundé, Cameroon

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Abstract: An efficient and affordable low carbon binder, based on Yaoundé local excavation earth, that achieves sufficient mechanical strength and water resistance for rendering applications has been formulated. Blends of Portland cement (PC) and laterite calcined at 750°C (CL) with varying weight ratios were investigated. The pozzolanic reaction was detected when replacing up to 70% PC by CL. The research investigated laterite sand mortar formulations, with varying proportion of fine particles. The strength of mortar pastes containing 40% and 100% PC in the binder reached the same level. The compressive strength increased with decreasing proportion of fine particles, and reached the maximum value of 10.2 MPa when the laterite sand grain size is larger than 100µm. The water absorption tests by capillarity showed that the formulation belongs to class Wc2 mortar, for all the laterite sand granulometries. The water absorption by capillarity coefficient decreased with increasing fines proportion: the highest value of 0.051 kg/(m².min^{0.5}) was obtained when the laterite sand contains no fine particles. Furthermore, the study explored the reuse potential of the grinded mortar: the fines showed pozzolanic properties and can be used as supplementary cementitious material, and the largest particles are suitable for lime stabilization.

Keywords: low carbon binder; calcined laterite; pozzolanic reaction; laterite sand mortar; water resistance; mechanical strength; circular economy.

1. Introduction

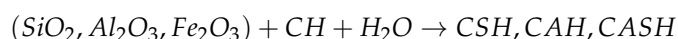
The widespread use of portland cement in concrete [1] combined with the depletion of non renewable mineral resources like sand or gravels, whose mining impacts on human health and natural ecosystems [2], presents significant challenges and motivates the development of alternative building systems based on circular economy.

In Yaoundé, Cameroon, where the increasing population growth rate reached 4.5% in 2020 [3], rapid urbanization has led to the development and saturation of precarious neighborhoods, mainly composed of poto poto shelters vulnerable to the hydric stress related to the tropical situation of the city [4]. Moreover, sand and gravel extraction in Cameroon severely impact the environment, particularly through the degradation of mangroves, which are areas of high ecological importance. Indeed, they contribute, among other things, to carbon sequestration. Their alteration leads to harmful consequences: degradation of biodiversity, increased coastal erosion, reduction in fish production and in soil fertility [5]. In this context, it is important to develop low-carbon binders based on circular waste management, in order to protect natural resources and reduce CO₂ emissions. To meet this objective, a valuable resource is available in Yaoundé : the kaolinite-rich excavated soil, that is available in abundance in 12 quarries with an estimated volume of almost 50000m³ [6], and that already showed great interest in the building sector.

Indeed, Lateritic soil is primarily used for compressed earth blocks (CEB) manufacturing. Different types of stabilization have been investigated in the literature [7] : mechanical stabilization that consists in compacting the soil with optimum water content [8,9], physical stabilization through granulometry control [10] or the addition of fibers that act at the macroscopic level [11,12], and chemical stabilization such as the addition of portland cement [9,10,13], lime [14], fly ash [15] or the use of geopolymer binder [16] for instance. According to the Cameroonian standard NC 102-115 (2007), the minimum compressive strength required for compressed unstabilized laterite blocks is 2 MPa, while the compressive strength should reach 4MPa for compressed stabilized earth bricks [13]. The mechanical resistance reported in the literature for unstabilized laterite blocks fulfil the standard requirement, however, such blocks melt when immersed in water [6,8,9]. This fact has been verified in a preliminary study of the present project: the mechanical resistance of CEB made from lateritic soil extracted at Yaoundé reached 4,77 MPa, but did not resist 24 hours water immersion. With a minimum cement stabilisation of 6%, CEB ally mechanical resistance and water stability [6,8,9]. External stabilisation has been investigated : 6 to 10% CEB was incorporated in the outer part of the bloc with a thickness varying from 0.75 mm to 2.25 mm while the inner part remained unstabilised. According to the study, a stabilisation crown of 2.25 mm thickness with 8% cement enabled to meet the construction standards in terms of mechanical strength and water resistance [8]. In this work, the development of an external stabilisation solution is investigated in the form of a rendering mortar.

Other valorization axis have been proposed in the literature: lateritic sand can be recycled as fine aggregates in cement concrete [17,18] and the fine fraction of kaolinite rich laterite, consisting of grains passing through a 100 μm sieve, can be activated by thermal treatment and constitutes an efficient precursor for geopolymerization [19–26] or can be used as supplementary cementitious material in cement based concrete [27–31]. In fine river sand mortars, replacing portland cement by 50% calcined laterite enabled to achieve 5.5 MPa strength [28]. However, raw laterite mortars with a similar cement content led to higher compressive strength [32], indicating that raw laterite is an efficient substitute to sand river in mortars.

In this context, this work focuses on the development of a rendering mortar based on a low carbon binder. Among the different valorization approaches that have been described in the literature, the development of cementitious systems has been investigated. This choice is motivated by the pozzolanic activity that laterite fines exhibit after appropriate thermal and mechanical treatments, based on material and physical characterization. In cementitious systems, portlandite $Ca(OH)_2$ is part of the hydration products of portland cement and is able to react with the reactive silicon, aluminum and iron oxides (SiO_2 , Al_2O_3 and Fe_2O_3) of pozzolanic materials in the presence of water, according to the pozzolanic reaction:



where CH stands for calcium hydroxyde $Ca(OH)_2$, H for water, and CSH, CAH, CASH stand for calcium silicate hydrate, calcium aluminate hydrate and calcium alumino-silicate according to cement notations. The developed binder is a mix of calcined laterite blended with portland cement. The lowest cement ratio, ensuring mechanical performance, is determined. The efficiency of the developed binder is measured by the mechanical resistance and the water resistance of lateritic sand based mortars with varying granulometry. To finish with, promising recycling strategies are presented.

2. Materials and Methods

2.1. Materials

2.1.1. Raw Materials

Laterite was collected in Yaoundé (GPS coordinates 343°19.1' N and 1132°00.0' E), crushed in a ceramic mortar and sieved with BS 100 µm. Two sieving methods were used : dry sieving enabled to achieve rapid partial sieving of raw laterite, whereas wet sieving enabled to fully sieve the raw laterite. The non passing fraction was used as lateritic sand, whereas fines with particle size smaller than 100 µm entered the binder formulation.

Laterite fines were calcined in a Solo 111-23/13/40 electric furnace at temperatures ranging from 500 to 750 °C during four hours. After calcination, the laterite fines cooled in open air and were sieved to BS 100 µm for disagglomeration.

Portland cement was purchased from a Yaoundé local supplier. Grade CEM II B-P 42.5 R was available at an affordable price and was therefore used for the present investigations. To evaluate the pozzolanic activity of the calcined laterite, KFN Nekapur hydrated calcium hydroxide was used.

2.1.2. Pozzolanic Activity of Calcined Laterite

The pozzolanic activity was determined by measuring the mechanical resistance of equal weight mixtures of lime and calcined laterite with calcination temperatures varying between 500°C and 750°C, designated as CL-500-CH to CL-750-CH, and water to solid ratio of 0.65. The pastes were cast into sealed cylindrical molds of 20 mm diameter and 40 mm height, stored at room temperature, and demolded after 7 days. The samples were cured at room temperature in plastic bags containing wet compresses. The samples were heated at 50°C for 24h prior to material characterization. For each formulation, 3 samples have been prepared.

2.1.3. Binder Pastes

Table 1 summarizes the composition of the blends that were cast and analysed throughout this study. The water to solid ratio, referred to as *w/s* was determined for each set of samples to ensure suitable workability of the mixes. Binder pastes were prepared according EN-196-1 standard. The binder pastes were casted into sealed cylindrical molds of 20 mm diameter and 40 mm height, stored at room temperature, and demolded after 7 days ageing. Afterwards, they were cured at room temperature in plastic bags. The samples were heated at 50°C for 24h before material characterization. For each formulation, 3 samples have been prepared.

Table 1. % composition by mass of binder pastes

label	CEM II	calcined laterite	w/b
CEM100	100	0	0.45
CEM20CL80	20	80	0.57
CEM30CL70	30	70	0.57
CEM40CL60	40	60	0.57

2.1.4. Mortar Pastes

Mortar pastes were prepared with the following weight ratio: one part of binder mixed with three parts of "lateritic sand", which was alternatively :

- excavation laterite containing 70% by mass fine particles, labelled as LAT70/30,
- partially sieved laterite that contained 60% by mass fine particles, labelled as LAT60/40,
- or the totally sieved laterite containing particles with grain sizes larger than 100µm, labelled as LAT0/100.

The water content, expressed as water to binder mass ratio, was adjusted to achieve similar workability for all formulations. Table 2 details the weight percent composition of the binder, the laterite sand granulometry and the water content, measured as the ratio between the mass of water (w) and the mass of binder (b).

Table 2. % Mortar pastes description.

Label	Binder % weight composition		Lateritic sand granulometry (% particule size distribution)		w/b
	CEM II	Calcined lat-erite	< 100µm	> 100µm	
CEM100-LAT 60/40	100	0	60	40	1.35
CEM40- LAT 60/40	40	60	60	40	1.35
CEM40- LAT 70/30	40	60	70	30	1.98
CEM40- LAT 0/100	40	60	0	100	0.88

Mortar pastes were prepared in a planetary mixer according to EN 196-1 standard. The blend was cast into 40 mm x40 mm x160 mm prismatic molds. The samples were covered with a plastic foil during 24h and then demolded. The prisms were sealed in plastic bags until 28 days ageing. 3 hours prior to the mechanical testing the samples were in ambient laboratory conditions. For each formulation, 3 samples have been prepared.

2.1.5. Reuse Potential of End of Life Grinded Mortar

The hardened CEM40- LAT 0/100 mortar after 28 days of cure has been used to consider the possibility of closing the life cycle loop of the developed mortar formulation. To this extent, the mortar has been grinded using a A077-01 micro deval abrasion machine, at a speed of 100 r.p.m. during 30 minutes.

Three formulations have been tested to assess the potential of reuse of mortar fines particles smaller than 100µm, with the following mass compositions and water ratio to achieve suitable workability:

- 75% lime and 25% mortar fines, referred to as CH75MF25, with a water to solid ratio of 0.5;
- 75% CEM and 25% limestone filler, referred to as CEM75LF25,with a water to solid ratio of 0.345;
- 75% CEM and 25% mortar fines, referred to as CEM75MF25, with a water to solid ratio of 0.345.

The sample preparation and storage are described in subsection 2.1.3.

Prismatic samples of grinded mortar with particle sizes smaller than 4mm stabilised with 15% hydrated lime have been casted and stored as described in subsection 2.1.4. The water content, measured as the ratio between the mass of water and the mass of solid was 0.30. The sample preparation and storage are described in subsection 2.1.4.

2.2. Characterization Methods

Particle size was investigated using Malvern panalytical mastersizer 3000. Ethanol was used as dispersent and refractive index 1.58 was assumed.

In order to qualify the reactivity of the laterite fines, water demand, that is a semi-quantitative test giving an indirect measure of specific surface area of the particles, was performed. 50 g of powder was mixed with water in order to reach the plasticity limit. The ratio of the corresponding amount of water over the mass of powder is referred to as the water demand.

Oxide content was measured with a S2 PUMA Brucker spectrometer.

The diffraction patterns were obtained using the Bruker D2 Phaser diffractometer, with a Cu tube (30kV, 10mA) and a Ni filter. The recordings were made for 2θ ranging from 10° to 55° (increment

0.02s, time per step 0.5s).
Spectrum two Perkin Elmer spectrometer was used to analyse raw laterite.
Thermo-gravimetric analysis was carried out using the Netzsch TG 209 F3 Tarsus thermo-microbalance, under nitrogen atmosphere. The temperature ranged from 20 to 950°C with a heating rate of 5°C/min, followed by a 60 min step at 950°C.
The compression resistance of cylindrical and prismatic samples were assessed using Walter+Bai LFM 400 Press, according to EN ISO 6892-1 standard. A displacement rate of 2mm/min was prescribed for cylindrical samples and a loading rate of 50 N/s was applied to prismatic molds.
Water absorption tests by capillarity were performed according to EN 15801 standard.

3. Results and Discussion

3.1. Raw Material Analysis

3.1.1. Particle Size

Lateritic Sand

Wet sieving of raw laterite enabled to assess the proportion of fines, with particle size smaller than 100µm, which amounts to 70% by mass. Figure 1 shows the particle size distribution curve for the particles larger than 100µm present in raw excavation laterite.

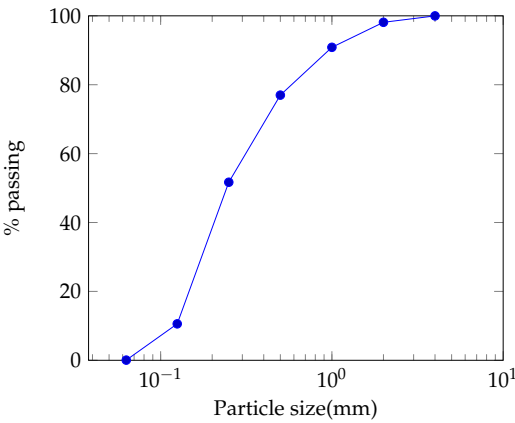


Figure 1. Laterite particle size distribution curve

Lateritic Fines

Granulometry and specific surface area are key parameters driving the pozzolanic activity. The average particle size d_{50} obtained for crude laterite fines and calcined laterite fines at 750° were 10.4 and 20.6 µm respectively. The average particle size is smaller for crude laterite than for calcined laterite. This is related to an agglomeration effect reported elsewhere [25,26]. One can note that the d_{50} values obtained for crude and calcined laterite fines are higher than the d_{50} value of metakaolin that is 4.35 µm [33].
Water demand, which is an indirect measure of the specific surface area, is 0.52 for crude laterite fines and 0.63 for calcined laterite fines. The higher water demand obtained for calcined laterite attests that the calcination increased the reactivity. Due to the high value of water demand of calcined laterite, the water to solid ratio will be carefully determined for each formulation in order to achieve a suitable workability.

3.1.2. XRF

XRF analysis of CEM, laterite, and metakaolin are presented on Table 3. Laterite exhibits high contents of SiO_2 , Al_2O_3 and Fe_2O_3 , the sum of the three oxide contents exceeding 70%. Upon calcina-

tion, the presence of these free and reactive oxides are responsible of the pozzolanic activity of laterite and enable to consider low cement ratios in this study.

Table 3. XRF analysis of raw materials - percent oxide composition by mass

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	TiO ₂	Na ₂ O	K ₂ O	P ₂ O ₅	Cl
CL	45.43	34.20	15.76	0.07	0.49	0.23	2.15	0.00	0.70	0.54	0.11
CEM	23.06	6.55	7.71	49.2	4.26	4.62	1.36	1.19	0.69	0.43	0.11

3.1.3. XRD

Figure 2 shows the XRD pattern of crude laterite and laterite calcined at 500°, 600° and 750°, referred to as CL-500, CL 600 and CL-750. The presence of kaolinite is detected through the diffraction peaks located at 12.5 °, 20 °, 21.2 °, 25.3 °, 35 °, 38.4 ° and 45.5° that disappear upon calcination. After calcination, there is also the transformation of goethite to hematite. Goethite reflections are detected at 33.5 ° and 36 ° in crude laterite pattern and hematite is visible at 19.8 °, 33.3 ° and 35.7 ° in calcined laterite patterns. Quartz reflections are visible at 20.8°, 25.2 °, 26.7°, 39.4 °, 42.5° and 50°.

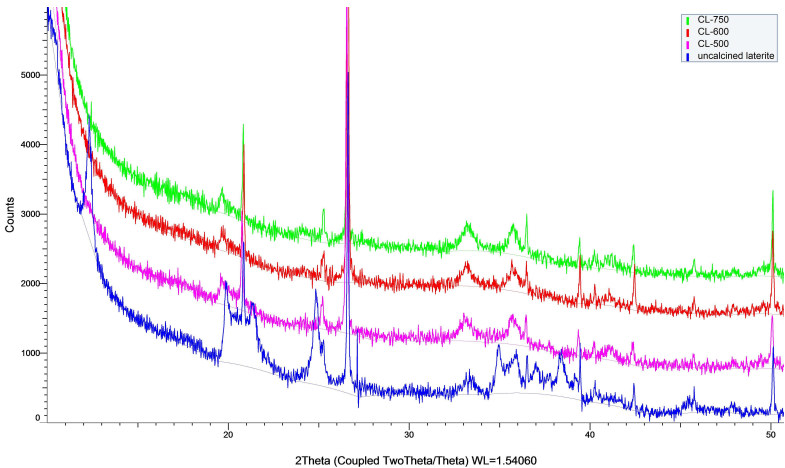


Figure 2. XRD pattern of crude and calcined laterite for three calcination temperatures : 500, 600 and 750°

3.1.4. FTIR

The FTIR spectrum of crude and calcined laterite are presented on Figure 3. The presence of kaolinite is detected through a set of well-resolved bands, that disappear or shift upon calcination[31,34–38]:

- OH stretching bands located at 3686, 3651 and 3610 cm^{-1} . These bands disappear upon calcination : this accounts for deshydroxylation of laterite;
- Si-O deformation bands located at 1119, 1028, 1001 and 684 cm^{-1} . Upon calcination these narrow bands are replaced by a broad peak located at 1036 cm^{-1} , 1045 cm^{-1} and 1051 cm^{-1} when the calcination temperature is 500°, 600° and 750° respectively. The shift to higher wavelength is a sign for the phase transformation from kaolinite to metakaolin;
- Al-OH band located at 909 cm^{-1} that disappear upon calcination;
- the strong narrow peak located at 526 cm^{-1} is related to the Al-O-Si deformation band, this peak translates to 777 cm^{-1} , which is related with a change in Al coordination;
- the band located at 460 cm^{-1} is related to Si-O-Si vibration modes, upon calcination this band transforms into a broad band of medium intensity located at 533 cm^{-1} , 545 cm^{-1} and 558 cm^{-1} when the calcination temperature is 500°, 600° and 750°. The shift of Si-O-Si vibration mode to higher wavelength attests for the appearance of an amorphous structure.

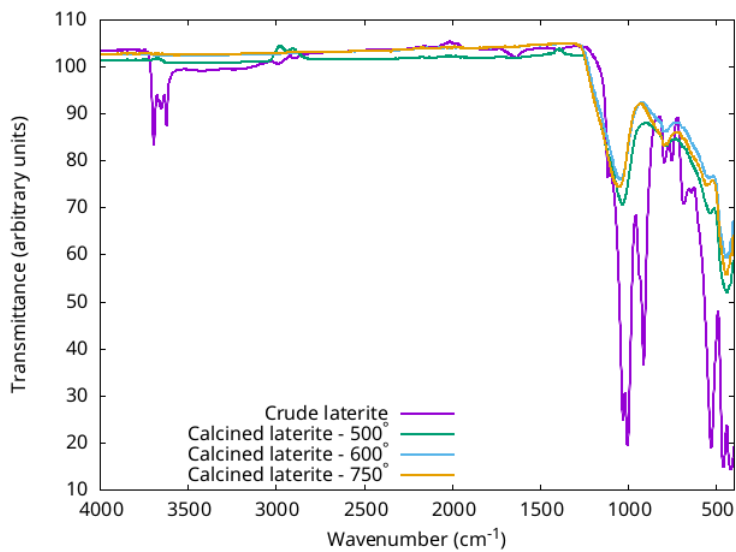


Figure 3. FTIR spectrum of crude laterite and calcined laterite for three calcination temperatures : 500°, 600° and 750°.

3.1.5. DTG

Figure 4 presents the DTG analysis of crude and calcined laterite for calcination temperatures ranging from 500 to 750 °C. The crude laterite curve exhibits three peaks, as already reported elsewhere ([39]):

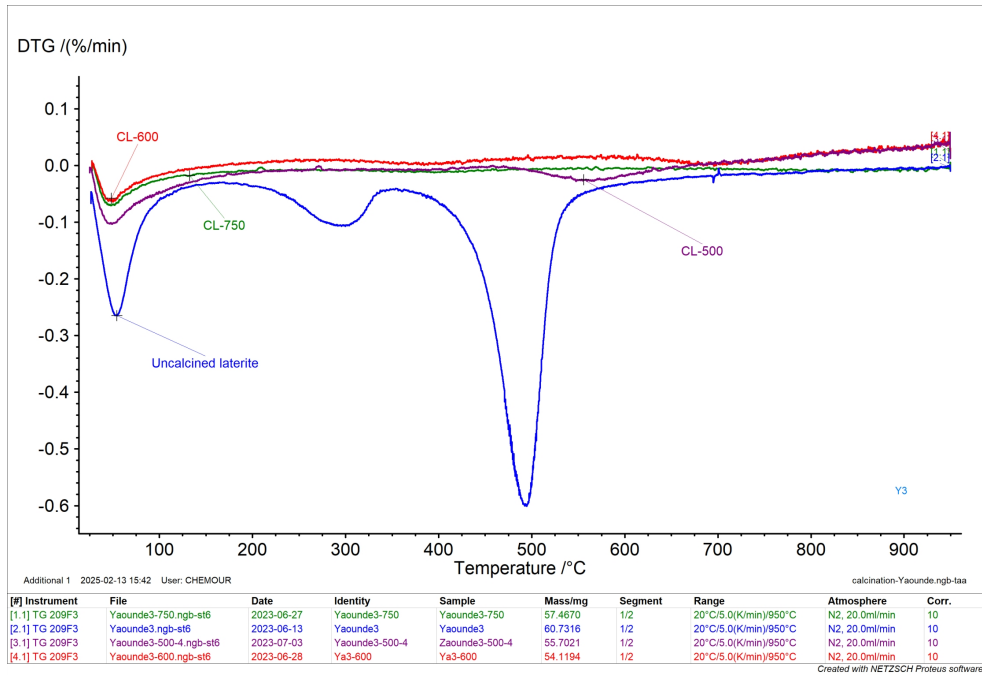


Figure 4. DTG curves of crude laterite and calcined laterite at 500°C, 600°C, 750°C

- the first peak between 25 and 100°C which corresponds to the loss of adsorbed water;
- the second peak between 225°C and 325°C corresponds to the decomposition of organic matter and of goethite to hematite;
- the peak between 400°C and 600°C corresponds to the dehydroxylation of kaolinite.

The kaolinite deshydroxylation peak appears on the crude laterite curve, whereas it completely disappeared when the calcination temperature is higher than 600 °C.

3.2. Pozzolanic Activity of Calcined Laterite

In the literature, the pozzolanic activity of calcined laterite has been assessed [40,41]. In order to define an accurate range for the cement substitution by calcined laterite, pozzolanic activity of CL was assessed according to the procedure described on subsection 2.1.2.

The mechanical strength reported on Figure 5 reveals the occurring of the pozzolanic reaction. As shown in the material characterization tests, calcination induces the transformation of phyllosilicate groups into reactive oxides capable of reacting with $Ca(OH)_2$ in the presence of water to form the possible hydration products : CSH, CASH, CAH . In the literature lower values of compressive strength have been reported for metakaolin-lime blends, ranging from 8 to 12 MPa, for water to solid ratio of 1 [42,43]. This may be related to several causes discussed in the literature : the presence of iron oxydes improves the pozzolanic activity of calcined kaolin [44], the unreacted quartz and iron hydrates present in the laterite fines act as microaggregates and improve the strength [10],the occurrence of early age carbonation process that hinders the pozzolanic reaction [33,45].

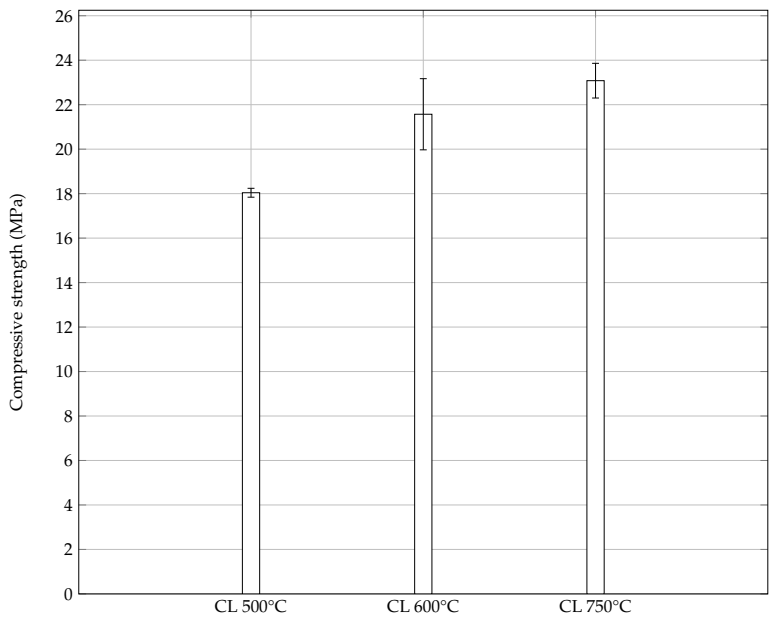


Figure 5. Reactivity of calcined laterite

3.3. Eco-Binder Design

As decribed in Table 1, the first set of blends is caracterized by water to solid ratio of 0.57 for calcined laterite blended cement pastes with cement ratios ranging from 20% to 40% and 0.45 for the blend containing 100% cement. These values ensure a suitable workability for all blends.

Figure 6 shows the compressive strength of calcined blended laterite with cement ratios ranging from 20% to 100%. Pozzolanic activity is revealed for blends containing 30% and 40% of cement : indeed an increase of 30% in compressive strength is recorded between the seventh and twenty-eighth day of curing. Figure 6 shows that the compressive strength linearly increases with increasing cement content up to 40%. The blends containing 100% CEM on one hand and 40% cement and 60% calcined laterite on the other hand exhibit a similar compressive strength for equivalent workability.

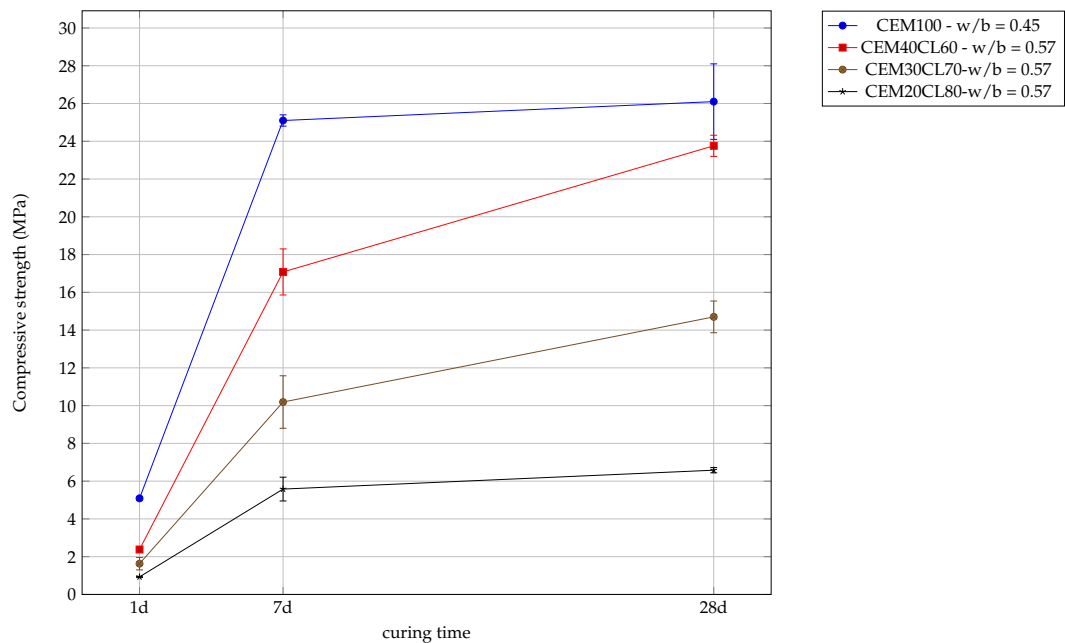


Figure 6. Evolution compressive strength of calcined laterite blended cement pastes containing 100, 40, 30, 20 weight percent cement with similar workability at 1day, 7 days and 28 days of curing.

Figure 7 shows the XRD curves of the pastes containing 30%, 40% and 100% cement. As expected, excess portlandite was detected in the cement paste containing only CEM, through the reflection peaks located at 18°, 34° and 47.2°. In the blends containing calcined laterite these peaks were not visible, meaning that no portlandite is detected: it was consumed through the pozzolanic reaction. The reaction of the excess portlandite and calcined laterite, as from 30% replacement of cement by calcined laterite has been reported elsewhere [28,30]. In the binder composed of 100% cement, the presence of unreacted di- and tri-calcium silicates is visible in a set of low intensity peaks located around 29°, 32.1° [46,47].

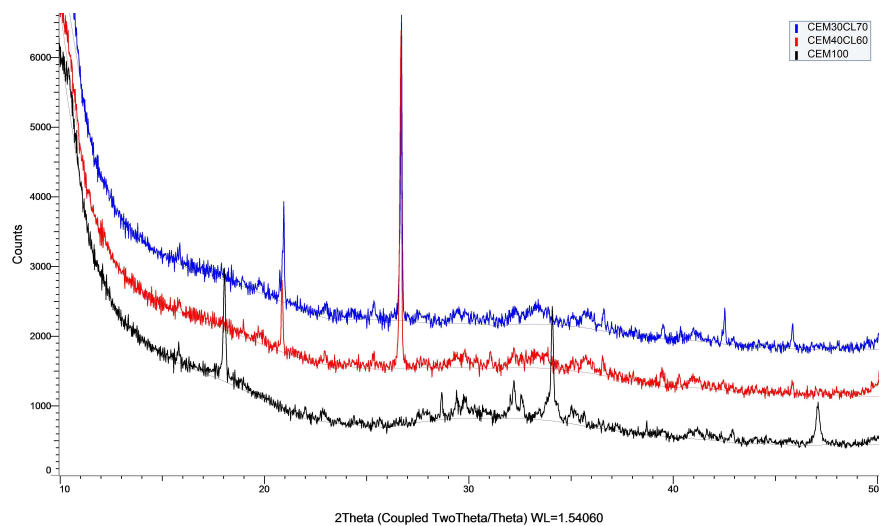


Figure 7. XRD curves of calcined laterite blended cement- with cement ratio varying between 30% and 100%

3.4. Mortar Pastes

3.4.1. Mechanical Resistance

Figure 8 shows the compressive strength measured at 1 day and 28 days respectively of the CEM100-LAT60/40 and CEM40-LAT60/40 mortar formulations described on Table 2, obtained with partially sieved laterite as lateritic sand. Water ratio was the same for the two formulations. The same mechanical resistance was obtained for the two mortar blends.

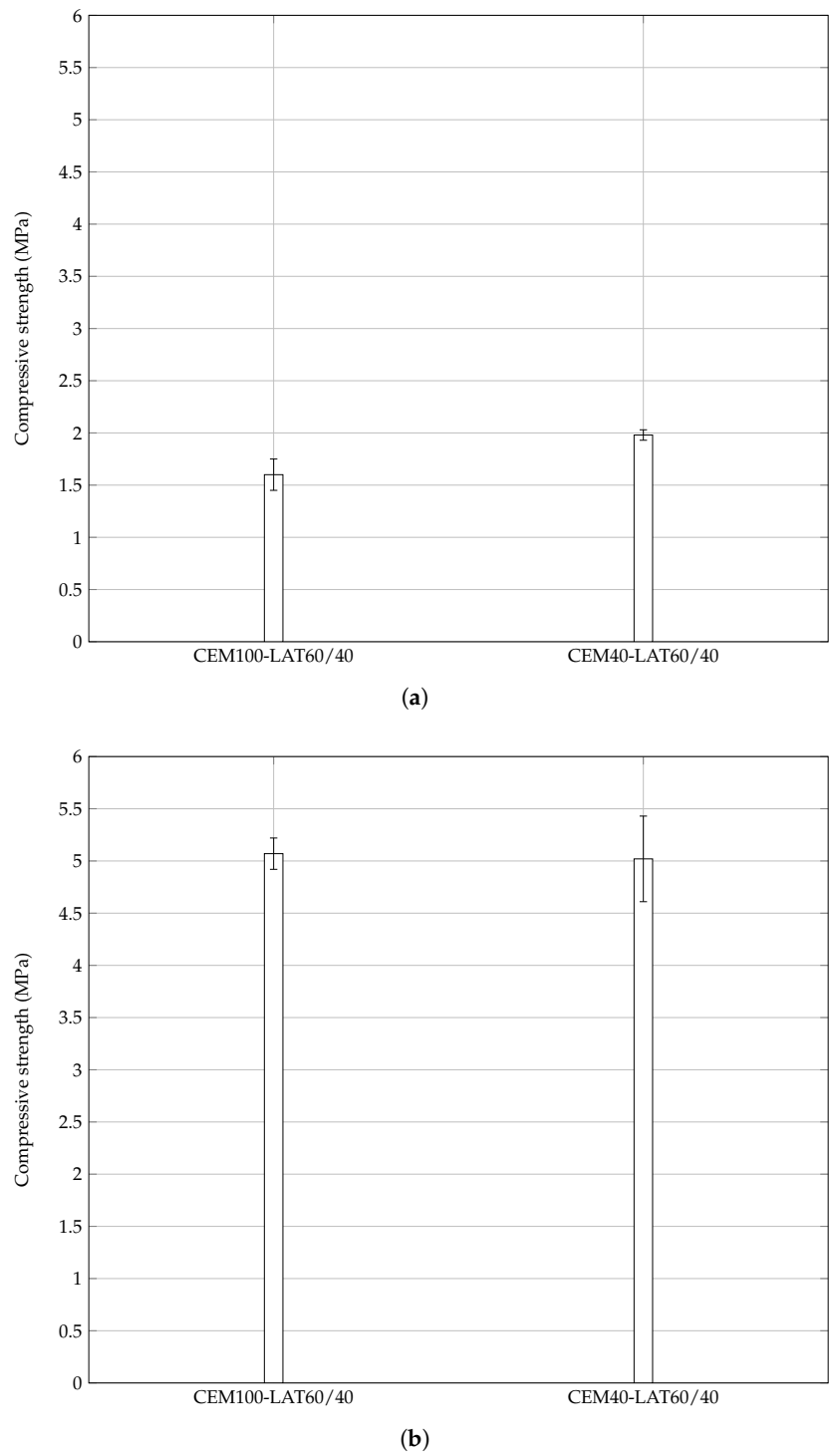


Figure 8. Compressive strength measured after 1 day (a) and 28 days (b) of curing for the following blends: 100% CEM - LAT60/40 and 40% CEM - LAT60/40. For both blends $e/l = 1.35$

Figure 9 shows the compressive strength of mortar blends formulations with 40% cement and 60% laterite binder, and with varying granulometry of lateritic sand, from raw laterite to completely sieved laterite with grain sizes larger than $100\mu m$ as described on Table 2. Water ratio was adapted for each blend in order to obtain the same workability : as the proportion of uncalcined fines increases, the water demand increases. Using raw laterite as source of coarse grains enables to achieve sufficient resistance for the formulation of a rendering mortar. However, using totally sieved laterite leads to the reduction of water ratio and in turn the improvement of mechanical properties.

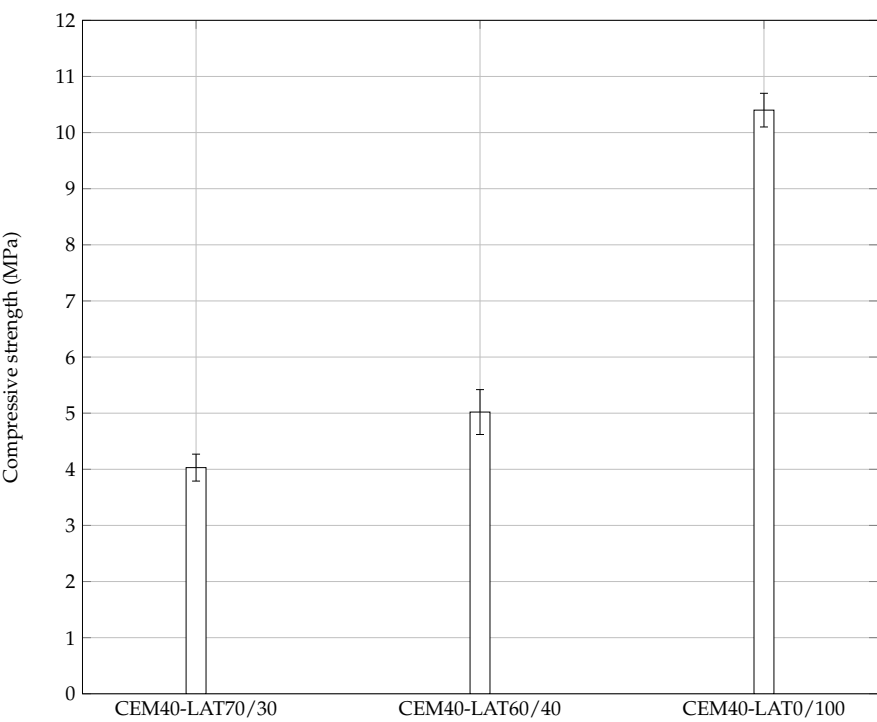


Figure 9. Compressive strength measured at 28 days curing for the following blends: 40 % CEM - LAT 70/30 - $e/l = 1.98$; 40% CEM - LAT60/40, - $e/l = 1.35$; 40% CEM - LAT0/100 - $e/l = 0.88$

3.4.2. Water Absorption by Capillarity Test

Table 4 shows the water absorption tests by capillarity performed on the mortar pastes described in Table 2 after 28 days of cure. It is shown that when the binder is composed of 100% CEM, the water absorption by capillarity coefficient is the lowest. When the binder is composed of 40% CEM and 60% calcined laterite, water absorption resistance is better when the lateritic sand granulometry contains the larger quantity of fine particles. This is in line with the ability of fine particles to avoid the formation of pores, thus improving the water absorption resistance.

Table 4. Water absorption by capillarity coefficient measured for the following mortar formulations : 100% CEM - LAT60/40, $e/l = 1.35$; 40% CEM - LAT60/40, $e/l = 1.35$; 40 % CEM - LAT 70/30 - $e/l = 1.98$; 40% CEM - LAT0/100, - $e/l = 0.88$

	Water absorption by capillarity coefficient $kg/(m^2.min^{0.5})$
CEM100-LAT40/60	0.011
CEM40-LAT30/70	0.026
CEM40-LAT40/60	0.039
CEM40-LAT100/0	0.051

For all the mortars formulations, the water absorption by capillarity coefficient, measured as the slope of the water absorption by capillarity curves at origin, are smaller than $0.2 \text{ kg} / (\text{m}^2 \cdot \text{t}^{0.5})$, which classify all the formulation as class W2 mortar according to EN998-1 standard, and ensures they are suitable for rendering applications.

3.5. Closing the Loop for the Developed Solution

The potential of reuse of the developed mortar is assessed here, according to the strategy described in section 2.1.5. Grinded mortar contains 40% of fine particles with size smaller than $100 \mu\text{m}$.

3.5.1. Pozzolanicity of Mortar Fines

Figure 10 show the compressive strength after 7 and 28 days of curing for the following blends: CEM75LF25, CEM75MF25 with water ratio of 0.345 and CH75MF25 with water ratio of 0.5. It is interesting to see that mortar fines have a more pronounced improvement effect on compressive strength of cement paste than limestone filler. Pozzolanic effect of mortar fines are also evidenced by the evolution of the blends CH25MF25 and CEM75MF25 mechanical properties: the compressive strength increase between 7 and 28 days amounts to 48% and 36% respectively.

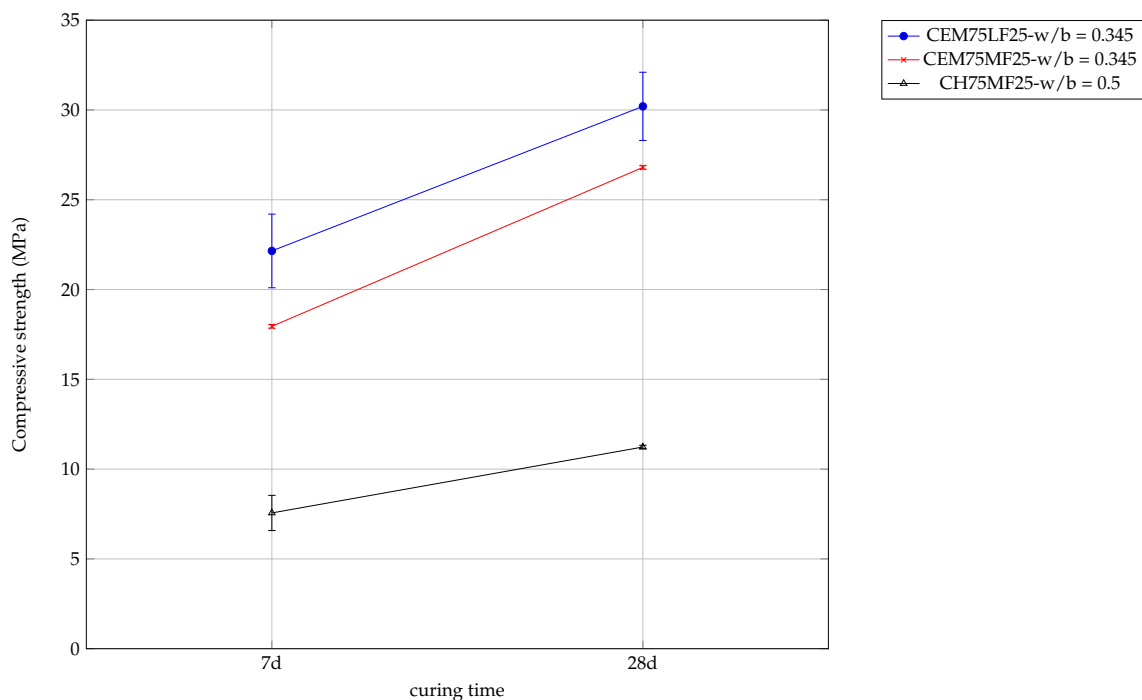


Figure 10. Compressive strength measured after 7 and 28 days of curing for the following blends: 75 % CEM - 25% limestone filler - $e/l = 0.345$; 75% CEM - 25% mortar fines - $e/l = 0.345$; 75% lime - 25% mortar fines - $e/l = 0.5$

Figure 11 shows the X-rays patterns of the following blends: CEM75LF25, CEM75MF25 and CH75MF25. Calcite reflection peaks are visible at 23.5° , 29.4° , 36° , 39.5° , 47.1° , 47.5° , 48.5° in the CEM75LF25 blend curve. In the cement blends, portlandite is visible through the reflection peaks located at 18.1° , 34.2° and 47.1° , however, the peak intensity is relatively smaller in the blend containing mortar fines, suggesting that the pozzolanic reaction occurred. In the calcined laterite and lime blend, the presence of kaolinite, present as a residue in the laterite sand, is detected through the 12° reflection peak, and calcium carbonate is visible at 23.5° , 36.6° , 39.5° , while a small quantity of calcium hydroxyde was detected, which accounts for the pozzolanic activity of the mortar fines.

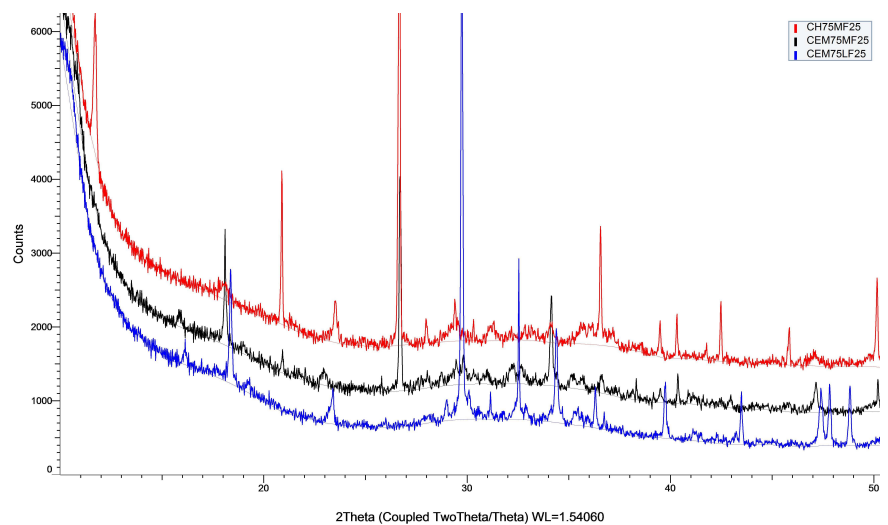


Figure 11. XRD patterns of the following blends: 75% CEM and 25% LF - w/b = 0.345, 75% CEM and 25% MF - w/b = 0.345 and 75% CH and 25% MF - w/b = 0.5

Figure 12 shows the DTG curves of the following blends: CEM75LF25, CEM75MF25 and CH75MF25. The decomposition of hydration products occur up to 160° for the cement blends and up to 300 ° for the lime blend. The presence of portlandite/ $Ca(OH)_2$ was observed in all blends through a peak located at around 440°, and calcium carbonates decomposition occurred at temperatures between 600° and 850°. The results are aligned with the XRD observations: calcium hydroxide partially reacts with the iron, aluminum and silicium reactive oxydes contained in the mortar fines, and partially undergoes carbonation mechanism. Carbonation occurs to a smaller extent and less quantity of portlandite was visible in the cement/mortar fines blend compared to the cement/limestone filler blend.

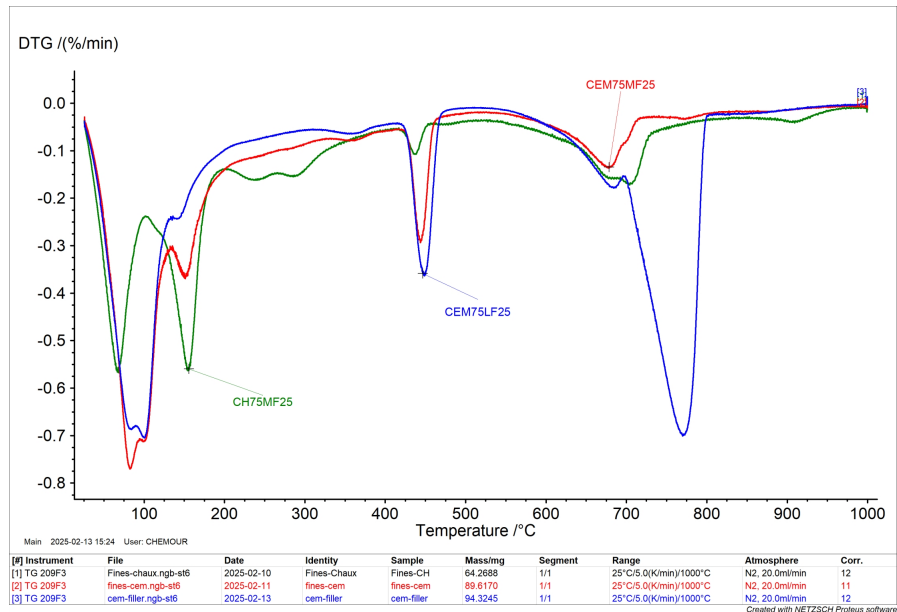


Figure 12. DTG curves of the following blends: 75% CEM and 25% LF - w/b = 0.345, 75% CEM and 25% MF - w/b = 0.345 and 75% CH and 25% MF - w/b = 0.5

3.5.2. Lime Stabilization of Grinded Mortar

Figure 13 shows the compressive strength of grinded mortar stabilised with 15% hydrated lime, with water/solid ratio of 0.30, measured at 7 and 28 days of curing. The strength is partly provided by the pozzolanic reaction of the mortar fines and lime, but also by the granular skeleton of the ground mortar, which is thought to be a good alternative to river sand.

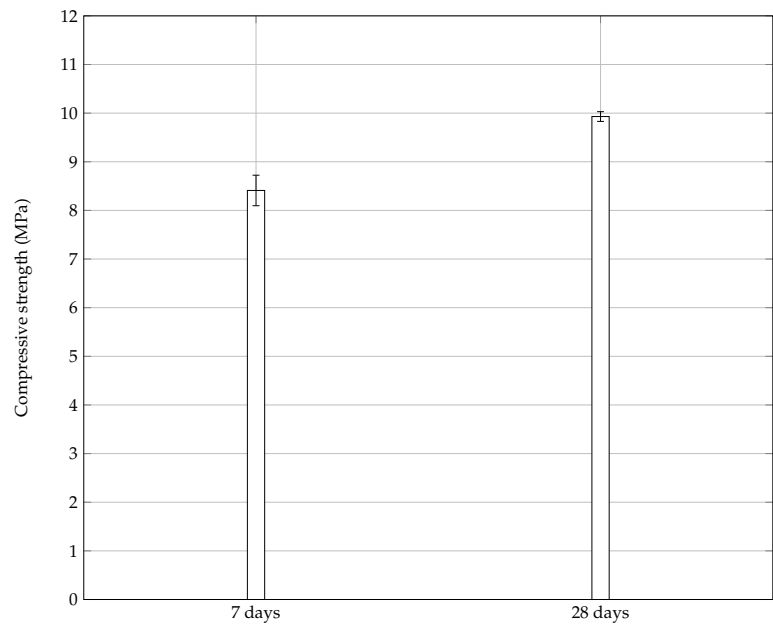


Figure 13. Compressive strength of grinded mortar stabilised with 15% hydrated lime, with water/solid ratio of 0.30, measured at 7 and 28 days of curing

3.5.3. Life Cycle of the Developed Solution

Figure 14 show the expected life cycle diagram of the developed solution. Environmental impact has been decreased by minimizing the CEM ratio in the binder. It has been shown that the grinded mortar fines show pozzolanic activity, and their incorporation in a cement formulation leads to improved compression resistance compared to the addition of limestone filler. Moreover, it has been shown that the larger part of the grinded mortar, with particle sizes larger than 100 μ m can be incorporated in a lime based rendering mortar, leading to improved compression performance. These concluding remarks open the path for further promising valorization potential of :

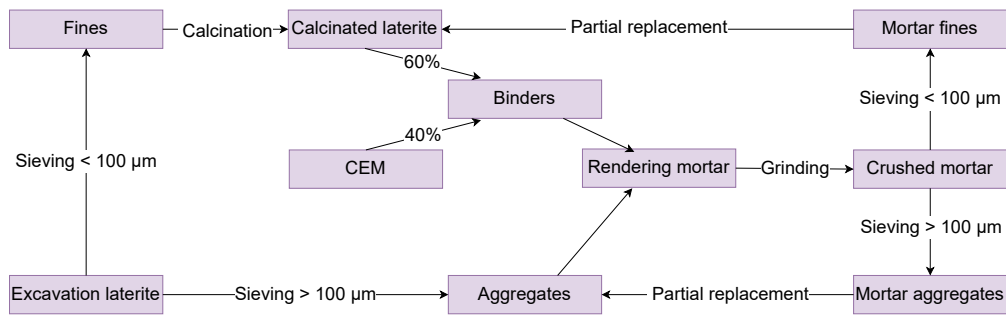


Figure 14. Life cycle of the developed rendering mortar

- the fines, with particle sizes smaller than 100 μ m, as partial replacement for the calcined laterite, leading to further energy savings;

- the larger aggregates, with sizes larger than 100 μ m as partial replacement for the lateritic sand.

4. Conclusions

The present work demonstrates the feasibility of reusing Yaoundé excavation earth to formulate a sustainable low cost rendering mortar, that does not require any specific equipment. A low carbon binder was formulated, based on the pozzolanic activity of calcined laterite, that is composed of reactive oxides capable of consuming the excess portlandite that is an hydration product of portland cement. It was highlighted that :

- replacing 70% of cement by calcined laterite enables to achieve acceptable mechanical strength for cement pastes;
- replacing 60% of cement by calcined laterite enables to achieve the same compression strength than a 100% cement paste for similar workability.

Lateritic sand mortars with a binder formulation containing 40% cement have been assessed, and lead to promising perspective regarding the mechanical strength and water resistance. Indeed, for similar workability, the compressive strength level is equivalent as if the binder was composed of cement only. Regardless of the fines content in the laterite sand, the mortars were all classified as W2 according to water absorption tests by capillarity. However, the higher the fines content, the lower the absorption by capillarity coefficient. To close the life cycle loop of mortar formulation developed in this study, the potential of reuse of the grinded mortar as been assessed :

- mortar fines are pozzolanic and can enter the binder formulation developed here as partial replacement of the calcined laterite, leading to further energy savings;
- the larger particles have the ability to substitute laterite sand in the developed rendering mortar, or equivalent mortars.

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Abbreviations

The following abbreviations are used in this manuscript:

PC	Portland cement
CL	calcined laterite
CH	Hydrated calcium hydroxyde
LATx/100-x	laterite sand containing x% of fines (<100 μ m)

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