Vol. 13(1), pp. 1-6, July-December, 2023
DOI: 10.5897/JCECT2023.0590
Article Number: F0F231271573
ISSN: 2141-2634

http://www.academicjournals.org/JCECT

ACADEMIC JOURNALS
expand your knowledge

Journal of Civil Engineering and Construction Technology

Full Length Research Paper

The effect of curing condition and use of additives on compressive strength of lime/pozzolana mortar

Mamoun E. E.[1], El Zamzami M. A.[2] and Abazar M. A. Daoud[1]*

[1]Faculty of Earth Sciences, Red Sea University, Sudan.
[2]Building and Road Research Institute, University of Khartoum, Sudan.

Received 1 March, 2023; Accepted 20 September, 2023

Previous studies have shown that the obsidian pozzolana of the Sabaloka area processes a high pozzolana index. Therefore, it was chosen to study the effect of its curing condition and use of additives on the compressive strength of lime pozzolana mortar. The investigation revealed that the strength of pozzolana mortar is affected positively or increases with the curing condition (humidity, time, and temperature); also the strength increases with the addition of torona (2, 5 and 10%) which the higher the strength reveals the higher the percentage of additives (10%). This is probably due to carbonation. The indirect curing gave higher strength than that of direct curing when we compared the carry fine fractions, respectively for indirect and direct curing. Regarding carbonation, the possibility of absorption of CO_2 from the atmosphere is greatly increased by the indirectly cured lime/pozzolana cubes because atmospheric CO_2 rates with lime to produce $caco_3$ which is accompanied by a gain in strength. The strength of pozzolana/lime mortar affected by the earing time. Long time of curing (120 days) gave the strength compared to the early strength 7 and 14 days; the same behaviour also for less finer (90 to 63 μ) gave 16 N/cm^2 for 120 days as compared to only 11 N/cm^2 for 7 days.

Key words: Pozzolana, curing condition, humidity, time, tempreture, torona, strength, carbonation.

INTRODUDION

The main aim of this paper is to study the effect of curing conditions and additives on the comprehensive strength of lime/pozzolana mortar from the Sabaloka area, Sudan.

ASTM C6118 (2023) gave a definition for Pozolana as a siliceous aluminous material which in itself possesses little or no cementitious value but will in finely divided form in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

According to Ellis and Tongbo (2018), Lea (1971), Grane (1980) and Varadarajan and Chatterjee (1991), pozzolanas are classified as natural or artificial pozzolanas. The natural pozzolanas, the subject of this paper, are materials of volcanic origin or sedimentary origin.

Materials of volcanic origin include obsidian, pumice, diamicite, and volcanic tuffs, whereas the materials of sedimentary origin include the diatomaceous earth. The

*Corresponding author. E-mail: abazarmohamed@alexu.edu.eg.

addition of pozzolanas to lime results in the formation of hydraulic lime/pozzolana cement due to the reaction between lime (CaO) and reactive silica (SiO_2) resulting in the formation of calcium silicate minerals. In the presence of water, hydration takes place at the surface of particles and therefore it is the total surface area of the cement particles that represents the materials available for hydration, thus the rate of hydration is influenced by the degree of fineness of cement particles, and consequently for a rapid development of strength, high fineness degree is necessary. Therefore, to get the required strength, the degree of fineness has to be carefully controlled (Neville, 1981; Qianmin et al., 2015). The effect of grinding of pozzolana on pozzolana quality has been studied by many researchers. Geng et al. (2020) and Robertson (1971) recommended grinding finer than 300 mesh for pumice and only 100 mesh for volcanic ash. Moreover, they emphasized that the lime must be freshly calcined.

Pozzolana materials have been used either in conjunction with lime as lime/pozzolana and cement or in replacement of Portland cement to produce Portland-Pozzolana cement. In both cases, the cement produced shows characteristic cementing properties especially when gauges with compressive strenth. There are a number of factors that affect the compressive strength of Lime/Pozzolana mortar. These factors have been found to influence the rate of reaction and eventually enhance, early and Late-strength mortars. These factors comprise the following: fineness, lime-pozzolana ratio, type and quality of pozzolana, curing conditions and additives.

Out of these factors, the curing condition and additives are significant properties since they influence most of the other factors and have a marked impact on the compressive strength of lime/pozzolana mortar. In view of the foregoing, they have decided to study the effect of curing conditions and additives can be the comprehensive strength of lime/pozzolana mortar.

Some researchers set a measure for fineness by determining the maximum retained on a certain sieve, whereas others adopted specific surface tests. For instance, the ASTM (1995, 2018) specifies the maximum percentage retained on 74 and 95. Sieves as 30 and 2%, respectively based on wet-sieving when the brick powder is used for mortars, the minimum percentage retained on 75 British Standard sieves is specified as pozzolana not to be greater than 50%. Siyam (1987), Robert (1990), Subhi (1978) and Walker and Pavía (2011) studied four different types of pozzolana and concluded that the strength of the four types increases with increased fineness. This was also confirmed by Hamid (1999), Nurhayat and Bulent (2005) and Sihem (2021).

MATERIALS AND METHODS

As the object of this paper is to study the effect of fineness on the strength of lime/pozzolana, the mortar test method is used for the determination of the compressive strength. Materials used in the present paper are natural pozzolana, lime and standard sand.

Pozzolana

Obsidian pozzolana from the Sabaloka area, 70 km North Khartoum, near Ban Gadeed Village, was selected because of its homogeneity and high pozzolanic index. Its chemical analysis and XRD pattern have been analyzed.

Lime

The source of the raw material for the production of lime (CaO) is the Blue Nile Marble (About 60 km south of El Damazin, Sudan). Its purity is of 98% CaO. The limestone was calcied at 1000°C for 6 h and the produced lime (CaO) was ground to pass a 90 mesh sieve.

Sand

The standard sand was prepared according to British Standard 882, (1996). The sand was sieved to pass 600 and retained on 800 sieve. The sieved fraction was washed to get rid of fine materials such as clays, salt, and organic impurities. It was then dried under direct sun rays for 24 h.

Preparation of lime/pozzolana mortar

Lime/Pozzolana mortars were prepared using a lime/pozzolana ratio of 1:3. In the mortar test 1:3 lime/pozzolana: Sand used the water in the mix corresponding to 0.52 by weight of the solid materials (lime + pozzolana). The batch was mixed thoroughly in dry and wet conditions. The test was carried out according to British Standard (2019) using 70.7 mm cubes which were vibrated for 2 min and then molded after 24 h. Curing was carried out in humid conditions for pre-determined periods after which the cubes were tested after 8, 14, 28, 60 and 120 days.

RESULTS AND DISCUSSION

Humidity

Moisture is known to be an essential factor in the development of strength. In order to study the effect of humidity, the curing of lime-pozzolana cement was carried out under two different conditions.

The first is direct curing where the cubes or specimens are completely immersed in water. The second is indirect curing where the cubes are not immersed in water but placed over an iron mesh situated 10 and 20 cm above the water level.

The results obtained were reported in Tables 1 and 2 and Figures 1 and 2. It can be seen that the 7-day strength reveals a higher strength for the indirect curing, the effect is more pronounced with the finer fractions. The strength reported are 10 s and 11.8 N/cm^2; a similar trend is observed after 14 and 28 days of strength. It is interesting to point out that the strength reported for the fine fraction (63) which is almost double that reported for the fractions ranging between 90 and 63. In all cases the

Table 1. The effect of curing on the compreesive strength of lime/pozzolana cement.

Type of cement	Degree of fineness (μ)	Average compressive strength (N/cm^2)		
		7 Days	14 Days	28 Days
Direct curing in water	90-63	10.45	15.67	27.17
Indirect contact in water (Indirect curing)	96-63	11.84	21.29	41.16
Direct curing in water	<63	18.46	30.31	64.43
Indirect contact in water (Indirect curing)	<63	25.60	42.15	83.20

Table 2. The compressive strength of lime-pozzolana cement at various tempretures.

Temperature of curing (°C)	Average Compressive Strength (N/cm^2)		
	7 Days	14 Days	28 Days
28	25.60	42.15	83.20
45	42.82	67.57	114.59
70	114.24	136.53	152.21

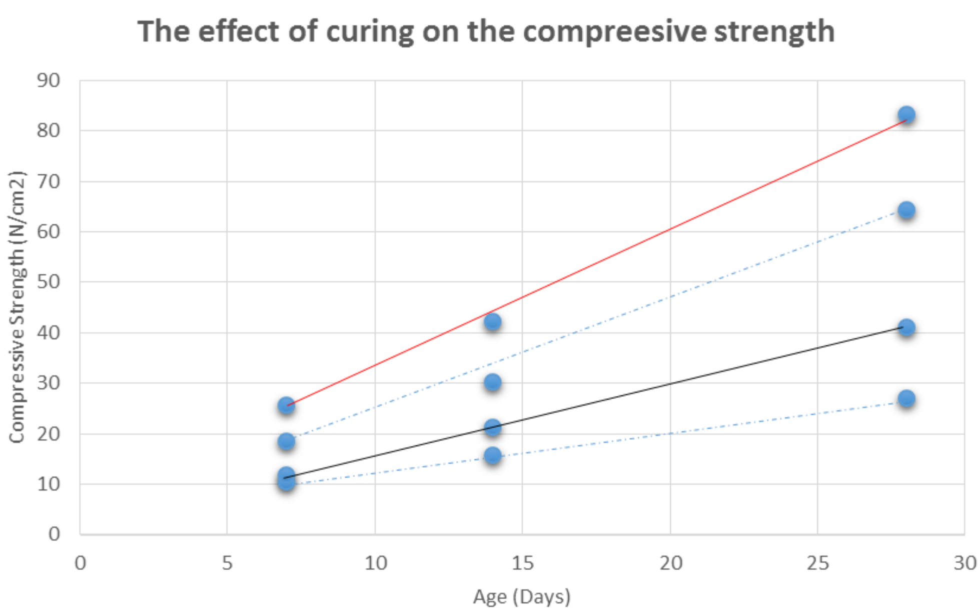

Figure 1. The relationship between the strength and the age. Red, Line indirect curing <63 μ; Black line, indirect curing, 96-63 μ.

indirect curing gave higher strength than that for direct curing shown in Table 1 and Figure 1, after comparing the cary fine fractions (<63) after 7 and 14 days (18.5 and 10.8), (25.6 and 11.8), (30.3 and 5.7), and (83 and 41) N/cm^2 , respectively for indirect and direct curing.

Regarding carbonation, the possibility of alsorption of CO_2 from the almosphere is greatly enhanced by the indirectly cured lime (pozzolana) cubes, because atmospheric CO_2 reacts with lime to produce $CaCO_3$ which is accompanied by gain in strength.

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \quad (1)$$

The formation of $CaCO_3$ was detected by XRD pattern (Figure 2), which revealed the presence of mineral calcite $CaCO_3$ in the sample which was indirectly cured for 28 days. So we can conclude that the formation of carbon

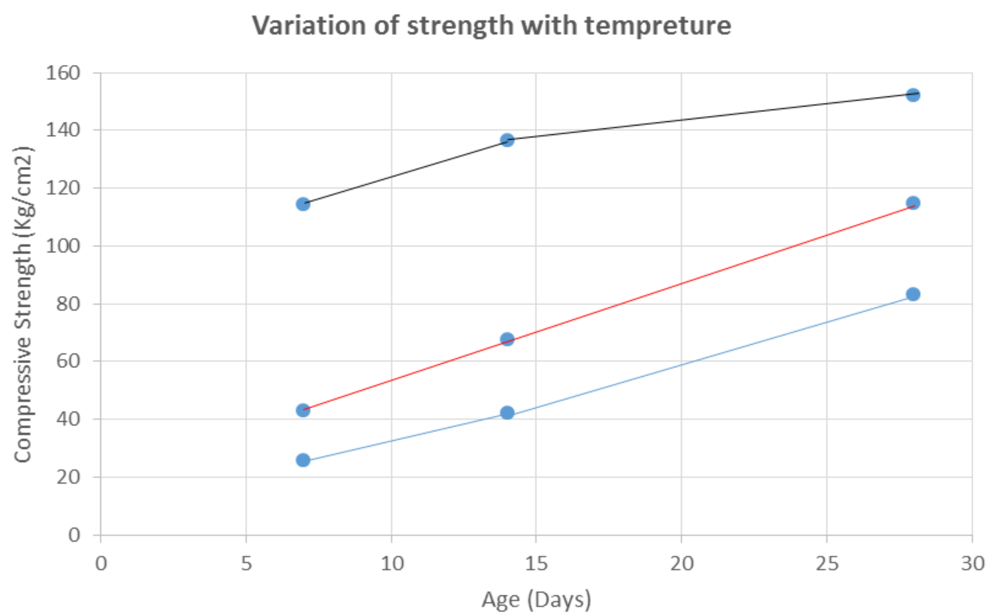

Figure 2. Various strength with temperature. Blue line, 28°C; Red, 45°C; Black, 70°C.

may increase the stregth of in direct cured lime/pozzolana cement.

The effect of fineness was studied using the following fineness range: Fraction greater than 250 (>250) classified as very coarse grain and denoted hereafter as p_1; fraction between 250 and 150 classifed as coarse-grain and denoted as p2; fraction between 150 and 90 classified as medium grain and denoted as p3; fraction between 90 and 63 classified as fine grain and denoted as p4; fraction less than 63 (<63) classified as very fine grain and denoted as p5.

Time

The strength of pozzolana/lime mortar affected by the earing time, long time of curing (120 days) gave the strength as compared to the early strength 7 and 14 days example: for the very fine pozzolana (<63 m), 1:3 lime/pozzolana gave 206 N/cm^2 as compared to only 23 N/cm^2 for 7 days curing.

The same behavior is also for less fine (90 to 63 μ) which gave 16 N/cm^2 for 120 days as compared to only 11 N/cm^2 for 7 days.

Temperature

The rate of strength development is very sensitive to the curing temperature. The reaction between lime and pozzolana to produce lime/pozzolana cement is affected by a change in the temperature of curing and consequently, the strength varies with a change in temperature.

In order to study the effect of temperature on the strength of lime pozzolana cement, tests were carried out for mortar cubes with very fine friction of pozzolana (<63 μ) and at a 1:2 lime-pozzolana ratio. The curing temperatures chosen were 28, 45 and 70°C to simulate room temperature, medium, and high temperature, respectively. The results obtained are reported in Table 2 and Figure 2.

It can be seen that at room temperature, the strength increases progressively from 25 to 83 N/cm^2 after 28 days. With an elevation of temperature to 45°C, the strength increases remarkably from 42 N/cm^2 after 7 days to N/cm^2 after 28 days. When comparing the strength obtained at 70°C to that at room temperature a very pronounced difference can be observed. The strength attained after 7 days is more than four times that attained at room temperature, more than three times for the 14 days strength, and nearly two times for the 28 days strength shown in Table 2. It is clear that the strength increased remarkably with increase of temperature of curing. The reason for the elevation of temperature accelerates the process of lime pozzolana reactions, and consequently increase the strength. Therefore the effect of temperature of curing can be used to improve the early strength of lime pozzolana cement.

Use of additives

In order to improve the early strength of cement pozzolana mixtures, certain additives were used such as cement gypsum salts ($NaCO_3$, etc.), water emulsion

Table 3. Additives percentage related to strength.

Torona percentage	Average compressive strength (N/cm^2)		
	7 Days	14 Days	28 Days
0	11.21	31.35	42.15
2	11.50	32.33	42.39
5	14.63	36.71	46.32
10	25.43	41.45	52.94

*At very fine fraction (90-63 μ); 1:2 lime pozzolana ratio.

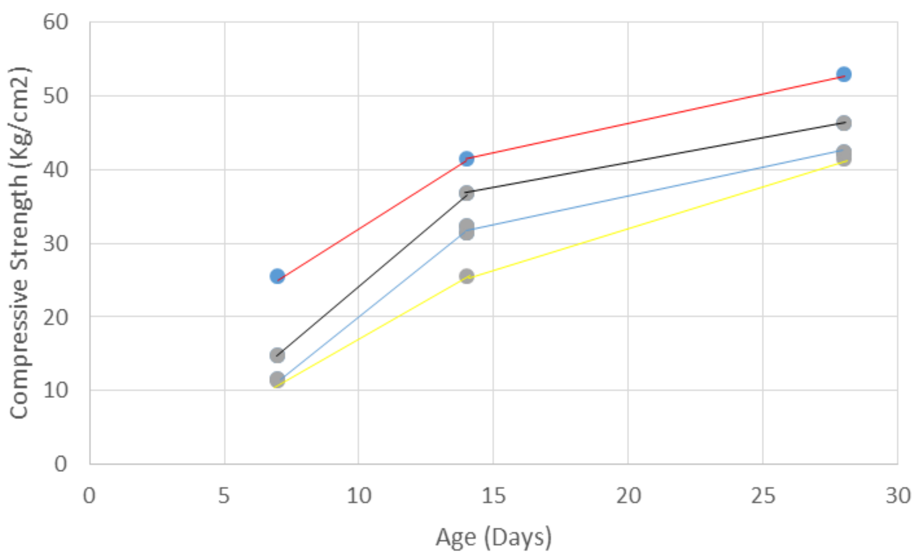

Figure 3. The effect of addition of torona on the strength of lime pozzolana cement. Red line 10% torona additives, Black 5%, Blue 2% and Yellow line 0% torona.

suspensions or solution.

Due to the availability of torona in Sudan, it was necessary to use it as an additive with a 1:3 lime/pozzolana ratio, various amounts of torona (Na_2CO_3, $NaHCO_3$), namely 2.5 and 10% were added, respectively. Mortar cubes were prepared, cured, and tested after 7, 14, and 28 days. Table 3 and Figure 3 show that the addition of 2% ($Na_2CO_3.NaHCO_3$) has virtually no effect on strength as compared to that of cement without additives. With the addition of 5%, an appreciable increase in the strength was noticed (15, 37 and 46 N/cm^2). However, the addition of 10% increased the strength remarkedly (25, 4 and 53 N/cm^2). The reported 7-day strength is more than twice the strength of lime-pozzolana cement alone.

A similar trend was observed after 14 and 28 days; however, the rate of increase is not comparable to that observed after 7 days.

The increase in the strength is probably associated with the formation and drying out of $CaCO_3$ as suggested by XRD as shown in Figure 4.

$$Ca(OH)_2 + Na_2CO_3 \longrightarrow CaCO_3 + 2Na(OH) \quad (2)$$

Conclusion

The study revealed that the lime-pozzolana cement needs special conditions for curing. In all cases, injured curing (e.g. not immersed in water) gave higher results than that reported for dived curing (that is, immersed in water). This might be associated with a reduction in porosity and an increase in carbonation, not only the type, but the temperature of curing has an effect on compressive strength which is increase in temperature is remarkably accompanied by an increase in strength and this is because a rise in temperature accelerates lime-pozzolana reaction with consequent increase in strength. Additives also affect the strength of lime-pozzolana cement. The addition of torona (Na_2CO_3, $NaHCO_3$) up to a maximum of 10% increases the compressive strength of lime-pozzolana cement. This is probably due to carbonation; the increase in the strength is probably

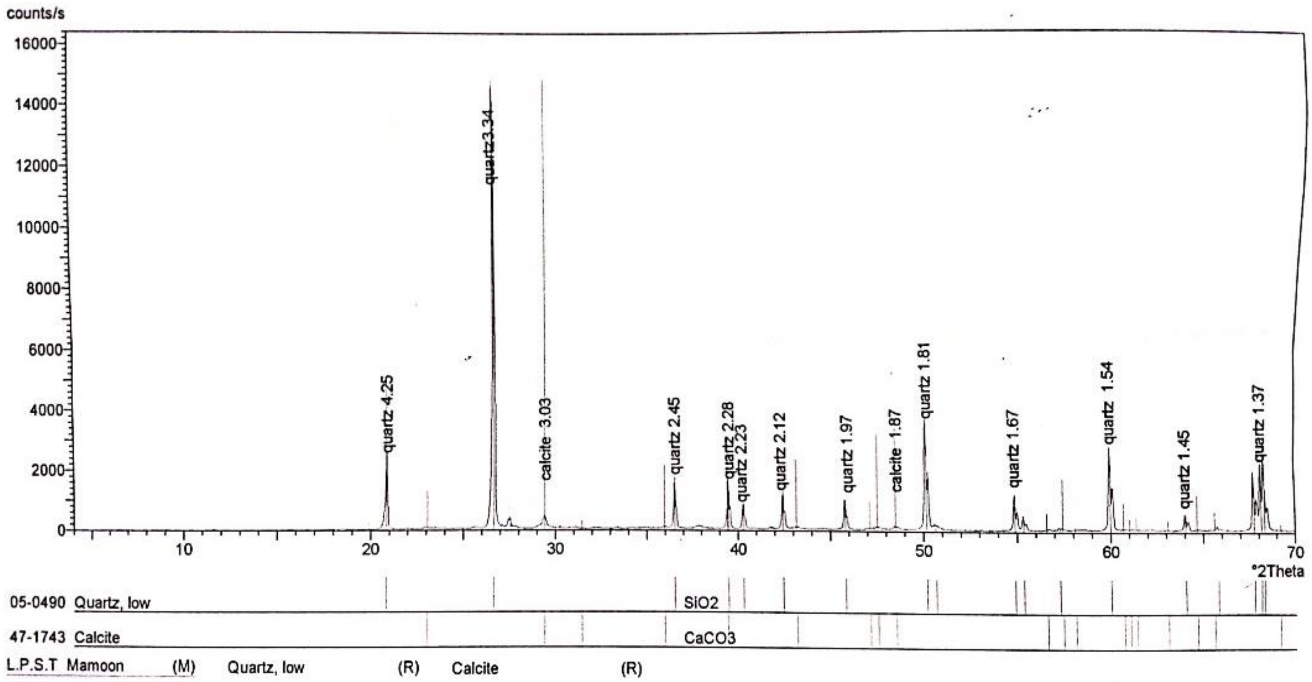

Figure 4. XRD patterns of obsidian at Ban Gadeed (Sabaloka).

associated with the formation and drying out of $CaCO_3$.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

ASTM C6118 (2023). Standard Specification for Coal and Raw or Cacined Natural Pozzolana for Use in Concrete. American Society of Testing Materials, USA.

ASTM C593. (1995). Specification for Lime – pozzolana Cement. American Society of Testing Materials, USA.

ASTM C1707 (2018). Standard Specification for Pozzolanic Hydraulic Lime for Structural Puposes. American Society of Testing Materials, USA.

British Standard (2019). Testing Hardnend and Concrete. Compressive Strength of Test Specimens. BS EN 1239-3.

British standard (1992). Specification of Aggrigates from Natural Sourse for Concrete. BS 882. No. 1

Ellis G,Tongbo S (2018). Alternative cement clinkers. Cement and Concrete Research Journal 14:27-39.

Grane PO (1980). Noncement – based hydraulic binder. Monographs on Appropriate Industrial Technology 12:48-57.

Hamid MH (1999). Contributions of Researchers in pozzolana cement in Sudan. Workshop in Uses of Pozzolana in Building Manufacture in Sudan, University of Khartoum, Sudan.

Lea FM (1971). The Chemistry of Cement and Cocrete. Chemical Publishing Company, London, 2nd , pp. 45-179.

Neville AM (1981). Properties of Cocrete, 5th ed. Pearon Education Ltd, Edinburg Gate, Essex, CM20 2J English.

Geng Y, Cui T, Zhang J, Wang J, Lyu X (2020). Effects of Mechanical Grinding on Pozzolanic Activity and Hydration Properties of Quartz. Advanced Powder Technology Journal 31(11):4500-4509. https://doi.org/10.1016/j.apt.2020.09.028

Nurhayat D, Bulent B (2005). Chemical Resistance of Pozzolana Plaster for Earthen Walls. Construction and Building Materials Journal 19(7):536-542. https://doi:10.1016/j.conbuildmat.2004.12.002

Varadarajan V, Chatterjee AK (1991). New Perspective of Hydraulic Binder Baed Composites. Transactions of the Indian Ceramic Society 50(2):27-37. https://doi.org/10.1080/0371750X.1991.10804481

Qianmin Ma, Rongxin G, Zhiman Z, Zhiwei L, Kecheng H (2015). Mechanical Properties of Concrete at High Tempreture-Areview. Construction and Building Materials 93(15):371-383. https://doi.org/10.1016/j.conbuildmat.2015.05.131

Robertson RHS (1971). Lime on small scale manufacturing. Process on Small Scale Manufacturing of Cementitious Materials, ll Publication London.

Robert L Day (1990). Pozzolans for Use in Low Cost Housing. International Development Research Centre, Ottawa, Canada.

Sihem H, Belkacem M, Said K, Carlos T, Mehmet S, Andre SG (2021). The effect of content and fineness of natural pozzolana on the rheological, mechanical, and durability properties of self-compacting mortar. Journal of Building Engineering 44:103276.

Siyam AHA (1987). pozzolana Stabilizeb Blocks for Low cost Housing. M.Sc.Thesis, Building and Road Research Institute, University of Khartoum. Sudan. (Unpublished Thesis).

Subhi MR, Al Jabbari (1978). Use of Lime Pozzolana for Plastering. Building Research Centre, Scientific Research Foundation, Iraq (Unpublished)

Walker R. Pavía S. (2011). Physical properties and reactivity of pozzolans, and their influence on the properties of lime–pozzolan pastes. Materials and Structures 44(6):1139-1150. https://doi.org/10.1617/s11527-010-9689-2