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Case study

Valorization of mud from Fergoug dam in manufacturing mortars☆

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ABSTRACT

The production of calcined mud, with pozzolanic properties, from the large quantities of sediments dredged from Algerian dams, could be a good opportunity for the formulation of high performance mortars and pozzolanic concretes, with lower costs and less greenhouse gas (CO_2) emissions. The optimal temperatures selected for calcination were 750, 850 and 950 °C. The burning operation was continuous over a period of 3 h. Therefore, a series of physical, chemical, mechanical and microstructural analyses were conducted on sediment samples, collected from the waters of Fergoug dam. The results obtained from the analyses of the calcined mud, from the dam, allowed saying that mortars with different percentages of that mud represent a potential source of high reactivity pozzolanic materials.

1. Introduction

In view of the significant growth in the housing sector, Algeria has reached a domestic production of 18 million tons of cement per year, with a deficit of 5 million tons each year. To accommodate the growth of the market, the cement sector is trying to focus its technological developments on solutions that may help reduce the amount of clinker used in cement, by opting to substitute ordinary Portland cement for natural or artificial materials. The use of supplementary materials like pozzolans in concrete helps to reduce clinker production (and hence CO_2 emissions), avoids landfill disposal needs, and can improve the performance of new building materials and thus prolong the service life of buildings; all of which contributes to sustainable development [1]. The benefits of using natural pozzolan as cement replacement are often associated with shortcomings such as the need to moist-curing for longer time and a reduction of strength at early ages [2]. The valorization of dredged materials and their use in the construction sector is a topic that has attracted more and more researchers in recent years. Therefore, it is a research area which is in harmony with the concept of sustainable development. In recent years, siltation of dams in Algeria has become increasingly common and worrisome [3]. Like all mineral additions (pozzolan, limestone fillers, dairy, . . .), the calcined mud, a natural, ecological and inexpensive material, can be a binder for making mortars and concretes and thereby ensure a saving in the consumption of cement whose price continues to rise [4].

Algeria has now, more than 70 large dams with a total capacity of 7 billion cubic meters of water. But this volume of water is highly threatened by mud deposits estimated at 50 million m^3/year [5–8]. The mud must be considered now as a beneficial

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product and not a simple rejection whose difficulties of disposal or storage posed an environmental problem. The dredged mud can be used depending on the nature and particle size of the sediments and energy committed to the manufacture of cement and grinding is higher thus more expensive than that committed for the calcination of the mud [9]. As an alternative means of disposal it is proposed to use these alumina-silica-rich muds in replacement of the pozzolans traditionally employed in commercial Portland cement production. The muds can be used as active additions to prepare blended cements with suitable properties [10,11].

Several studies have been conducted recently to study the effect of mineral additives on the mechanical properties and resistance in aggressive environments of mortars and concretes. But few detailed studies on the performance of concrete and mortar based Algerian dams dredged sediment. In construction, the dam mud can be used for the manufacture of bricks, mortars, concretes. In roads it can be used as materials for embankments, shape layers, untreated or treated layers of roadways [4]. Generally, four main components are found in the mud of dams, namely the mineral matrix (quartz, feldspars or carbonates), the clay fraction (kaolinite, illite or smectite), the organic fraction (plant debris, microorganisms, fulvic and humic acids) and a certain amount of water, in different forms. However, only direct samplings and analyzes allow to precisely define the exact structure of dredged sediments [12,13]. Heat treatment of mud, whose objective is to develop an artificial pozzolana, consists in calcinating the sedimentary silt, at an optimum temperature, for a given period of time. By thermal activation of clay sediments, in the temperature range from 550 to 950 °C, it is possible to obtain phases rich in alumina and silica with partially disordered structures that allow for pozzolanic reactivity [14].

Partial substitution of ordinary Portland cement by calcined clays gives a void filler effect, improved hydration of Portland cement at an early age, and a pozzolanic reaction of calcined clays in the long run. Calcined clays, with phases rich in highly reactive aluminate, promote the formation of AFm-type phases and influence the microstructure of hydration products; this increases the chain length C-A-S-H, when Al replaces Si [15]. To overcome the deficit in the production of Portland cement and reduce its cost, the concern of the research is to develop a binder in which are incorporated natural resources such as the dams mud. This calcined mud improves long-term compressive strength and durability, because it gives rise to C-S-H 2nd generation that improve the filling of pores. Cement made from artificial pozzolan calcined vase Algerian dams turned out better than that based on natural pozzolan Beni Saf [16]. The valorization of these sediments, potential materials in civil engineering, allows saving energy, reducing the cost of cement, diminishing the greenhouse gas (CO_2), and at the same time getting rid of large undesirable amounts of sediments, previously removed by dredging and deposited upstream of the dam. If not taken away, these sediments will certainly lead to long-term degradation of the environment and pollute the countryside, particularly if the dredged mud contains contaminated materials, which will certainly pose an environmental and ecological threat; they are toxic to living organisms and agricultural lands [12].

The wilaya (province) of Mascara (Algeria) has got four dams; they have all been flooded by mud. The dam of Fergoug offers a distressing view due to its sedimentation rate, estimated at 95%. The initial storage capacity of this dam was 17 million m^3. In 2005, it underwent a dredging operation which allowed recovering 10 million cubic meters of sediments. Therefore, because of these huge quantities, the valorization of this dredged mud remains a real challenge. The particle size analysis shows that the 80 μm tamisat is of the order of 98%, which greatly reduces the energy of grinding relative to the cement; furthermore, mud of Fergoug is located close to two cement plants of western Algeria so economy is better [17]. Analyses of sediments collected from the bottom of the dam showed lithofacies such as sand, silt and clay of dolomitic nature and limestone. Their chemical analysis revealed the presence of compounds of silica, carbonates, lime, alumina, kaolinite, dolomite and some organic matter. In addition, mud showed an unstable mineralogical structure reactive to water in the presence of lime, due to thermal activation through calcination at 750 °C. Some amorphous combinations appeared parallel to lime (CaO), as well as certain new crystalline compounds, more or less stable [18].

The present work aims at evaluating the thermal activation potential of dredged sediments, especially the clay fraction of dam mud, to be used in making mortars by partial replacement of normal Portland cement by mud dredged from the Algerian dam of Fergoug. The choice of Fergoug dam is justified by its very advanced silting state, and thus its desilting is today an urgent operation. The possibility of using this kind of materials in the cement industry has not previously been addressed in the literature. To this end, the mud dragged from the bottom of the dam was calcined at different temperatures, i.e. 750, 850 and 950 °C, for 3 h, in order to study the potential valorization of dredged sediments. This may be an attractive alternative to use them in civil engineering as binders in order to improve the physical, chemical and mechanical characteristics of mortars on the one hand, and to reduce the consumption of clinker on the other.

Table 1
Chemical composition of cement.

Components	SiO_2	MgO	SO_3	K_2O	Na_2O	Al_2O_3	Fe_2O_3	CaO	LOI
Contents (%)	16.82	1.87	2.37	0.58	0.25	3,3	0,51	65,6	7,56

LOI; loss of ignition.

2. Materials and methods

2.1. Cement

The kind of cement used in the manufacture of mortars is a pure type of Portland cement CEM I 42.5, from the cement plant of Lafarge Algeria (also called Matine). This cement has a Blaine specific surface equal to 4298 cm^2/g and a density equal to 3.00. Its chemical composition was determined in the laboratory of the above mentioned cement plant, using the XRF analysis method (Table 1).

2.2. The mud

The selected Fergoug mud was homogenized, and all organic residues of grass removed. It was next dried, sterilized at 105 °C for 24 h, and crushed manually. After that, it was subjected to intense grinding in a disc mill and then passed through a 75-μ sieve. The calcination was carried out at the temperatures 750, 850 and 950 °C, in a static oven, set at a temperature ramp rate of 5 °C/min for a period of 3 h. The calcined mud obtained was kept away from moisture and air. The mineralogical composition of the uncalcined mud is determined by the XRD method and is represented by Fig. 1. XRD can estimate the quantity of clinker minerals more accurately than the traditional Bogue equations, which use the XRF chemical results. And the XRD method can also quickly analyze important compounds such as free lime which are time consuming to analyze by any other method. With advances in computer power and programming software the complex calculations required to estimate clinker phases have become faster and more accurate, enabling this method to be used in on-line analyzers for both clinker and cement. XRF and XRD methods measure different things, each giving different informations about the same sample. The XRD spectrum shows a predominance of silica (SiO_2) and kaolinite. The vase contains a small amount of calcite ($CaCO_3$) and mineral accessory (traces) is illite. This analysis confirms the authorization of the vase to be used as an addition having pozzolanic properties.

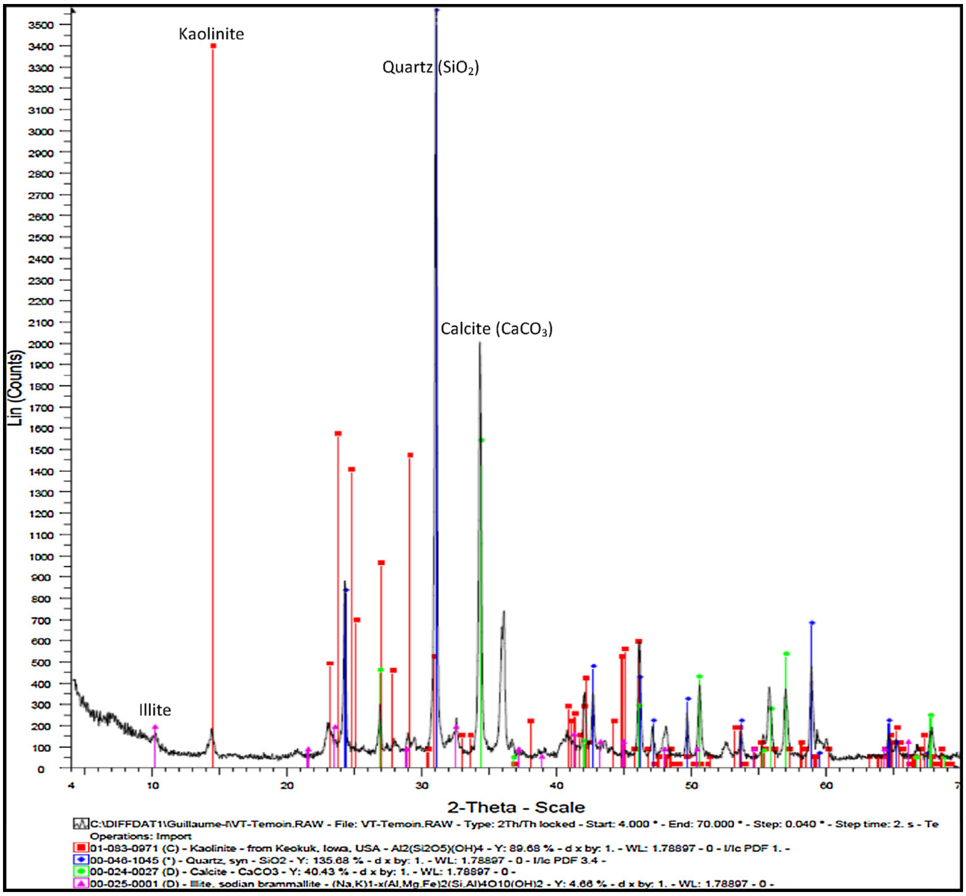

Fig. 1. X-ray diffractogram of natural mud.

2.2.1. Chemical compositions of different kinds of mud used

The chemical compositions of the different kinds of mud used in this study were determined by X-ray fluorescence (XRF). The X-ray fluorescence (XRF) is a non-destructive technique used to quantify the elemental composition of solid and liquid samples, (Table 2). The X-rays are used to excite the atoms in the sample, and make them emit X-rays with energies that are characteristic of each element present in the sample. The intensities and energies of these X-rays are then measured. Fig. 2 includes the percentages of the different oxides found in the mud under study. The three oxides SiO_2, Al_2O_3 and Fe_2O_3 are essential elements in the manufacture of Calcium Silicate Hydrate (C-S-H) gels upon hydration of cement. In addition to these major oxides, one notes a slight increase in the amount of lime (CaO) as a function of calcination temperature of mud. These changes in the chemical compositions of the different binders will certainly affect the behavior of the new cements made with mud from the dam of Fergoug.

On the other hand, it is well known that for pozzolan to be active, it must contain a total of more than 70% of all three main oxides, i.e. $(SiO_2)+(Al_2O_3)+(Fe_2O_3)>70\%$, according to standard ASTM C 618-03 [19]. This sum was found to be equal to 54.24, 62.26, 70.22, and 72.64 for natural mud (NM), CM750, CM850 and CM950, respectively. It is therefore concluded that the mud samples, calcined at 850 and 950 °C, have values close to the limit value of 70%, and hence can be active (Fig. 3).

2.3. Physical properties of different powders

Table 3 shows some physical properties of various powders used in this research work as densities, Blaine specific surface and residue on 45-μ sieve.

2.3.1. Density

The densities of the different mud samples were found to be lower than that of cement, because calcined mud is not as fine as cement. However, the densities of calcined mud are higher than that of natural mud (Table 3).

2.3.2. Specific surface area

The specific surface area decreases with calcination temperatures. Indeed, the fineness decreases while the temperature increases (Table 3).

2.3.3. Test of residue on 45-μ sieve

The test of residue on 45-μ sieve is another interpretation of the specific surface of the powder. This shows the importance of this physical quantity and its role in the hydration of cement in the short term, as well as the compactness and hardening of cementitious materials in the long run. Table 3, which summarizes the finenesses of different kinds of mud after passing through a 45 μm sieve, shows that the higher the calcination temperature of mud, the greater the percentage of elements thicker than 45 μm. This confirms the results obtained through the measurement of the Blaine fineness. Indeed, the higher the calcination temperature, the greater the residue on sieving.

2.4. Workability

The spreading tests on a shock table to get the workability of fresh mortar, according to standard ASTM C 1437-01 [20], was carried out by spreading a quantity of mortar and filling a truncated cone, of radii 8 and 7 cm, for the bottom and top faces, respectively, and 4 cm for the height. The spreading was determined by the following formula:

$$\Delta E\ (\%) = (D_2 - D_1)/D_1 \tag{1}$$

where:

D_1: initial diameter before shock (cm),
D_2: average of all 4 diameters aftershock (cm).

2.5. Preparation of mortars

Mortar specimens, of dimensions $(4 \times 4 \times 16)\ cm^3$, were made. Normal mortar was prepared according to standard NF P 15-403-96 [21], i.e. 450 ± 2 g of cement and 1350 ± 5 g of sand. The W/C ratio was set to 0.50 and kept constant (Table 4). The

Table 2
Elemental chemical composition of cement and different kinds of mud (%).

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	P_2O_5	TiO_2	LOI
NM	41.40	7.82	5.02	17.47	3.12	0.32	1.36	1.17	0.08	0.43	22.84
CM750	47.70	8.93	5.63	19.31	3.54	0.37	1.52	1.18	0.09	0.49	13.25
CM850	51.98	10.95	7.29	20.95	3.74	0.38	1.60	0.19	0.09	0.52	8.05
CM950	54.20	11.06	7.38	21.94	3.83	0.37	1.72	0.20	0.10	0.58	2.95

Note: NM is natural mud. CM750, CM850 and CM950 represent mud calcined at 750, 850 and 950 °C, respectively.

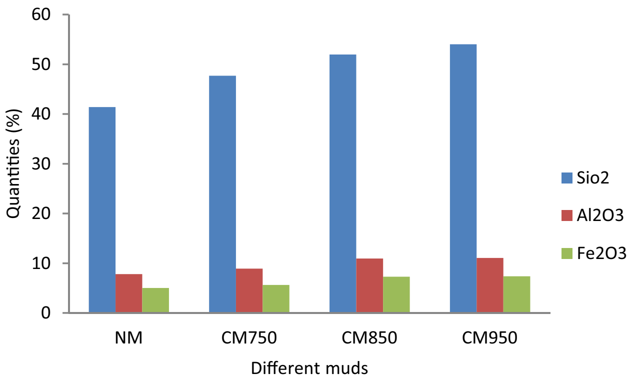

Fig. 2. Composition of major oxides in the mud under study.

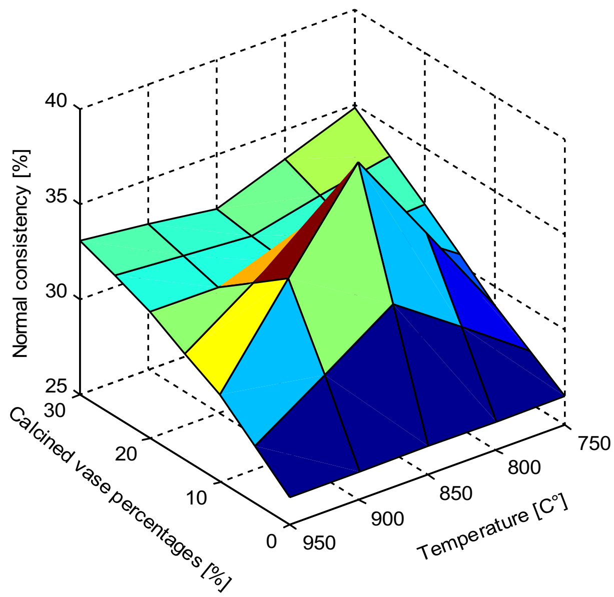

Fig. 3. Variation of normal consistency as a function of the rate of substitution of mud calcined at 750, 850, and 950 °C.

substitution rates of cement by mud were 0, 10, 20 and 30% by weight of Portland cement. After 24 h, the samples were removed from the molds and stored in trays containing water at the temperature (20.0 ± 2.0) °C. The specimens were placed on grids in such a way that water can reach the six faces.

2.5.1. Normal consistency

The results of the flow table (spread table) test, in accordance with standard ASTM C 1437-01 [20], show that mortar prepared with Portland cement, without any addition, has lower maneuverability than that made with calcined mud, when

Table 3
Physical properties of various powders.

Designation	Different powders				
	C	NM	CM750	CM850	CM950
Density	3,00	2,67	2,79	2,77	2,78
Blaine specific surface (cm^2/g)	4298	4500	4110	4030	3501
Refusal sieving through a sieve 45 μm (g)	–	5,1	12,3	12,5	13,6

Table 4
Composition of the studied mortars.

Mortars	Cement (g)	mud (g)	Sand (g)	Water (g)
M0	450	0	135	225
M10	405	45	135	225
M20	360	90	135	225
M30	315	135	135	225

Note: M0, M10, M20 and M30 represent mortars with 0, 10, 20 and 30% of mud, respectively.

the amount of water used is kept constant. Thus, the workability of mud mortars increases as the percentage of replacement of cement by mud rises, for all temperatures (Fig. 3). Therefore, increasing the substitution rate of cement by calcined mud requires higher amounts of water. For example, for mud calcined at 750 °C, this increase is around 9.43, 20.75 and 31.32% for mortars M10, M20 and M30 respectively, with regard to natural mortar (without addition).

The normal consistency increase, as the dosage of calcined mud raises, results from the calcination of mud at high temperatures. Indeed, when mud is calcined at temperatures beyond 100 °C, bound water is released, thus making mud avid for water. This leads to the formation of stable flocs in the binder paste and consequently, to trap a certain amount of water which is not available to lubricate the mixture. Thus, more water is needed to obtain a workable mortar mix. The formation of such flocs is essentially due to the presence of a large number of positive and negative charges on the binder surface; so they tend to flocculate when they are placed in the presence of a polar liquid, such as water [22].

2.5.2. Setting time

All binders were prepared in accordance with the recommendations of standard ASTM C1157- 2000 [23], which requires the setting time to be higher than 40 min and can extend up to 420 min. The results, shown in Fig. 4, clearly indicate a proportional increase in the initial and final setting times with the rise in the substitution rate of cement by calcined mud. For example, the substitution of 10, 20 and 30% of Portland cement by mud calcined at 750 °C, extends the initial setting time by about 15, 9 and 24%, and the final setting time by approximately 16, 16 and 63%, respectively, for the same substitution rates, compared to normal mortar (reference mortar, without calcined mud).

This behavior can be explained by the use of high temperature calcined mud and the decrease in the amount of Portland cement replaced by calcined mud. The substitution of Portland cement by compound binders requires a longer curing time for the composed pastes. The authors Laoufi [24], Senhadji [25] and Chihaoui [26] studied the setting times of cements containing supplementary cementitious materials (SCMs) and found results comparable with those reported in the present study.

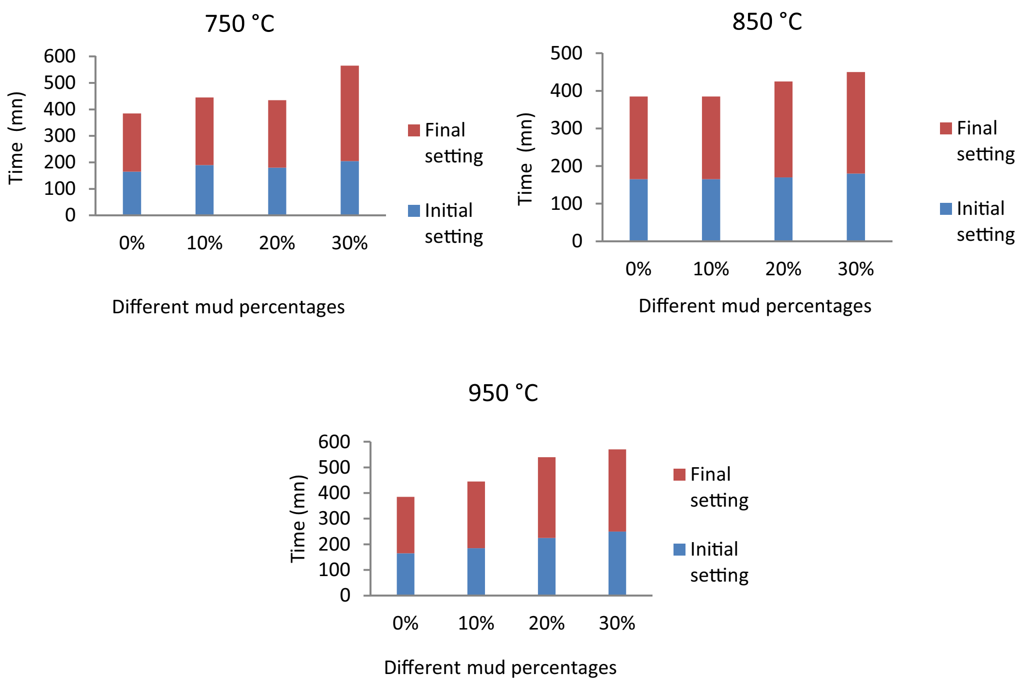

Fig. 4. Initial and final setting times of cement with mud calcined at 750, 850, 950 °C.

2.6. Mechanic performances

The compression strength and the flexural strength tests were performed according to standard ASTM C 109-13 [27]. Cubic mortar samples $(4 \times 4 \times 16)\,cm^3$, with replacement rates of 0, 10, 20 and 30% by weight of cement, were prepared. After 24 h, the samples were removed from the molds and stored in lime-saturated water, at the temperature $(20 \pm 2)\,°C$, until the due dates, i.e. 3, 7, 28 and 56 days. Each crushing test was performed on 3 samples, and the average compressive strength and flexural strength was recorded.

3. Results and analyses

3.1. X-ray

In Fig. 5 the XRD pattern of the raw and calcined silt is reported. X-ray diffraction pattern shows the presence of quartz, calcite, feldspars and clay minerals, in particular kaolinite and illite, as principal mineralogical phases for non-calcined sediments. X-ray diffraction tests were conducted on the raw and activated silt dredged at 750, 850 and 950 °C. The results revealed that all peaks of the kaolinite mineral disappeared at the mentioned range of temperatures. Therefore, dehydroxilation and transformation of kaolinite into metakaolin have been performed completely. Metakaolin is obtained by dehydroxilation of kaolin clay in the temperature range of 650–850 °C [28–32]. This temperature leads to a loss of chemical water, breakdown in the crystalline structure and consequently a phase transformation to amorphous with high reaction ability called metakaolin (AS_2 or $Al_2O_3.2SiO_2$). This phase transformation is due to the following reaction:

$$2SiO_2{\cdot}Al_2O_3{\cdot}2H_2O\ 2SiO_2{\cdot}Al_2O_3 + 2H_2O\uparrow \tag{2}$$

The intensity of kaolinite peaks in the raw silt is very strong, and the related pattern indicates the good quality of this material and the existence of weak amounts of impurities. Furthermore, from the aspect of dehydroxylation at 750, 850 and 950 °C heating temperatures, there was no noticeable difference between patterns of the heated materials.

3.2. DTA–TGA spectroscopy results

The differential thermal (DTA) and thermal gravimetry (TGA) analyses of the starting silt and calcined silt at 750, 850 and 950 °C are presented in Figs. 6 and 7 respectively. They show the thermal behaviour typical of kaolinite clays [33,34]. The interval [0 °C to 120 °C] showed the period of drying of the raw material which consisted to the disappearance of the water molecules. From [400 °C to 500 °C], the kaolinite changed into giving the new metakaolinite phase. Also from 600 °C to 800 °C, the raw material undergoes a reaction of carbonation with the atmospheric CO_2 gas. The overall result shows that the thermal treatment of the clay fractions at 750, 850 and 950 °C are enough to transform kaolinite into metakaolinite which is in agreement with the thermal analyses (DTA and TGA) results which show that the dehydroxylation of kaolinite starts from around 500 °C. The difference between natural clay and calcined clay seems to be connected with the presence of a clay mineral like kaolinite which transforms into metakaolinite after calcination.

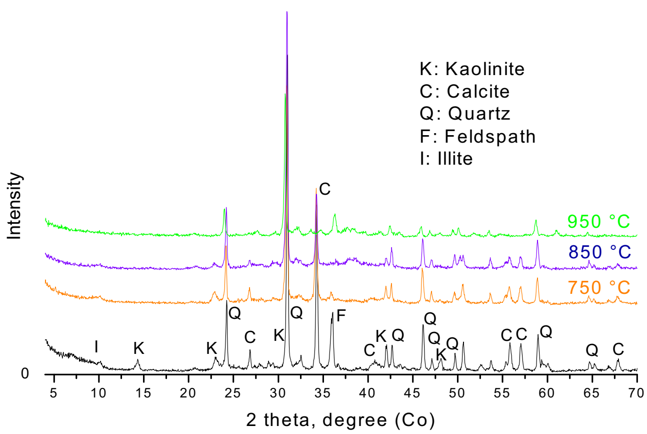

Fig. 5. X-ray diffractogram of Fergoug's mud of the starting silt (untreated) and thermally treated (calcinated) at 750, 850 and 950 °C.

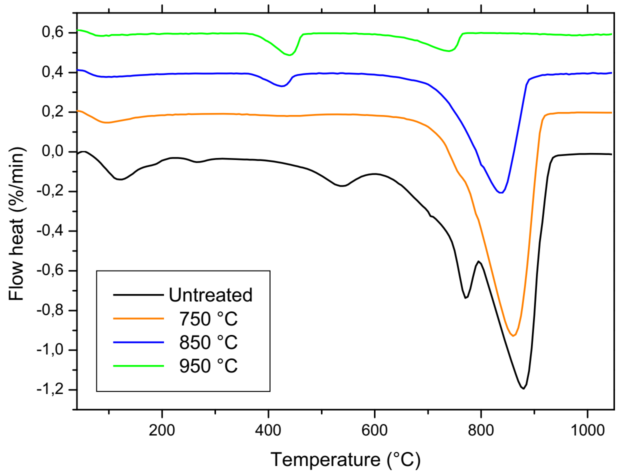

Fig. 6. DTA curve of the starting silt (untreated) and thermally treated (calcinated) at 750, 850, and 950 °C.

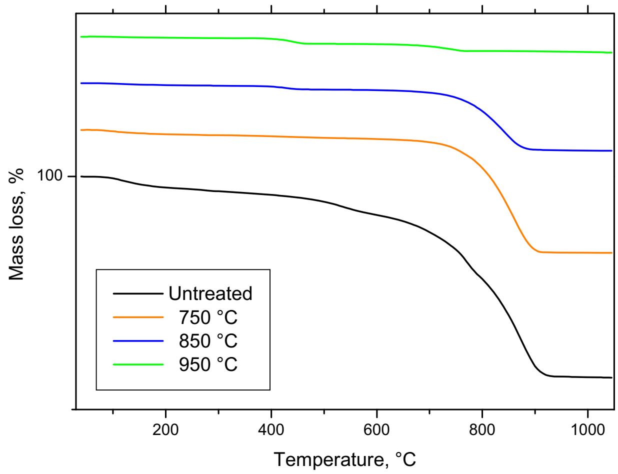

Fig. 7. TGA curve of the starting silt (untreated) and thermally treated (calcinated) at 750,850 and at 950 °C.

3.3. Mechanical performance

3.3.1. Compressive strengths of mortars

The results of the evolution of the compressive strength of mortar specimens, prepared with calcined mud, are shown in Figs. 8 and 9. From these figures, it is clearly seen that the mechanical performance of all mortars increases steadily with age; it shows no drop in the compressive strength.

From Fig. 8(a) we can draw the following remarks: It is the calcination of the mud at a temperature of 750 °C which yields the greatest compressive strengths of mortars to 10, 20 and 30% of silt at the age of 56 days. These compressive strengths, for substitution rates equal to 0, 10, 20 and 30% of cement by mud calcined at 750 °C, were found equal to 48.3, 44.5, 43.21 and 40.61, respectively, after 56 days. It is clearly seen that even when cement is replaced by large amounts of calcined mud (30%), its compressive strength does not decrease significantly, compared to its reference value (natural cement). At the young age (3 days), the compressive strengths of mortars at 10, 20 and 30% of mud remain low compared with the control mortar: it is normal because the pozzolanic reaction of artificial pozzolan (mud) did not yet triggered. At this calcination temperature of 750 °C, it is the mortar M10 with the mortar M20 which give the best compressive strengths of mortars containing artificial pozzolan.

From Fig. 8(b) we can draw the following remarks: The compressive strengths, for substitution rates equal to 0, 10, 20 and 30% of cement by mud calcined at 850 °C, were found equal to 48.3, 39.05, 39.76 and 39.82, respectively, after 56 days. This calcination temperature of 850 °C gave values of compressive strengths better than the calcination temperature of 950 °C but values lower than the calcination temperature of 950 °C at the age of 56 days. For this same calcination temperature (850 °C), it is the mortar M20 which gives the best compressive strengths of mortars containing artificial pozzolan. We can finally say

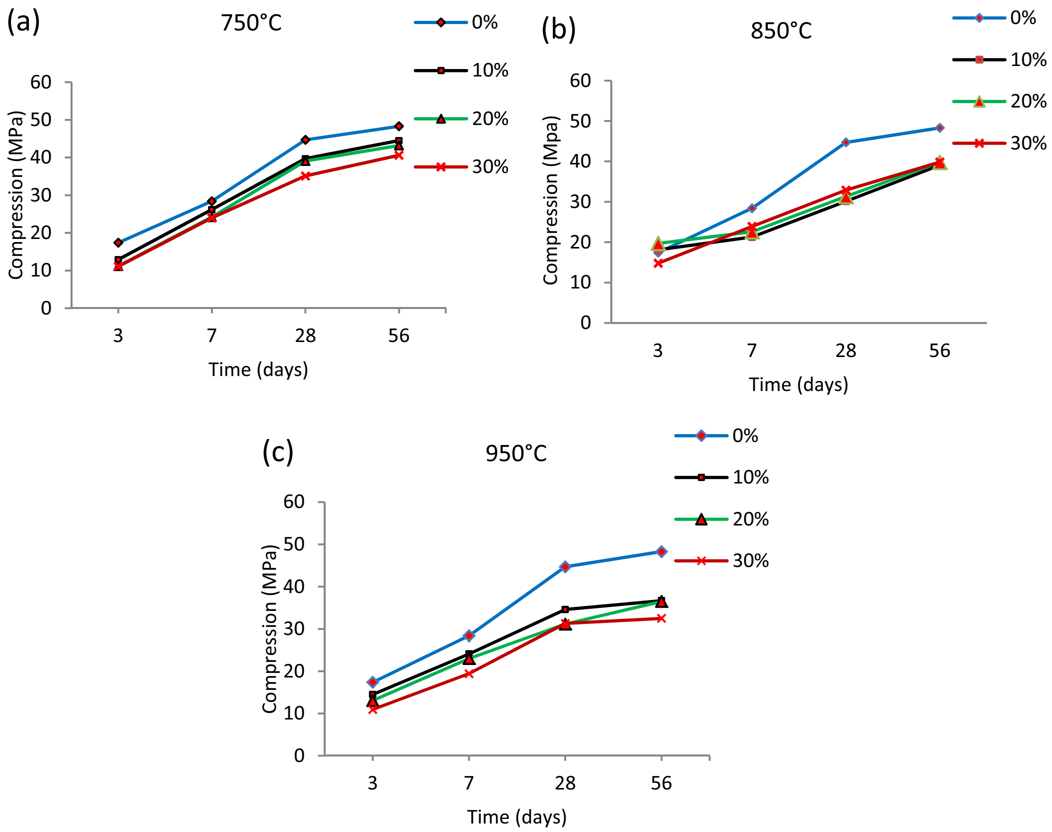

Fig. 8. Compressive strengths of mortars, with mud calcined at 750, 850 and 950 °C.

that the compressive strength values (56 days) of mortars containing artificial pozzolan remain weaker than the normal mortar M0.

From Fig. 8(c) we can draw the following remarks: The compressive strengths, for substitution rates equal to 0, 10, 20 and 30% of cement by mud calcined at 950 °C, were found equal to 48.30, 36.70, 36.50 and 32.50, respectively, after 56 days. These compressive strength values (56 days) of mortars containing artificial pozzolan remain the weaker compared to the normal mortar M0. Of all calcination temperatures, the calcination temperature at 950 °C gave the lowest compressive strengths and this, practically for all ages studied that is to say, 3, 7, 28 and 56 days.

The Fig. 9 clearly indicates that mortars M10 and M20, with calcined mud substitution, exhibit the best performances, after M0 for practically all temperatures. One can also clearly note that the compressive strengths, for the calcination temperatures of 750 and 850 °C are better than that at 950 °C. But the calcination temperature of 750 °C is better than that at 850 °C.

Therefore, calcined mud has played a major role in improving the mechanical performance, with a lower cost, because clinker requires more energy for its formation and its grinding. The decrease in the strength of pozzolanic mortars with respect to reference mortar M0 is mainly due to the slow activity of artificial pozzolan. This phenomenon is attributed to the interaction of the reactive silica, which is in the glassy part of artificial pozzolan, with $Ca(OH)_2$ released by the hydration of Portland cement. This allows artificial pozzolan to fix lime. The pozzolanic reaction is not predominant in the young age, and this gives a less intense hydration at young ages and induces low strengths. However, strength can be improved through extended grinding (high finesse), high cure temperature, or with the use of chemical activators [35,36].

3.3.2. Tensile strength

The results of the flexural strength evolution of mortar specimens prepared with calcined mud, and kept in lime-saturated water are clearly shown in Fig. 10 where it is easily seen that the mechanical performance (flexural strength) of all mortars increase steadily with age, and show no drop in strength. From our study, it can be stated that in general the incorporation of calcined mud helps in improving the flexural strengths, at all substitution rates.

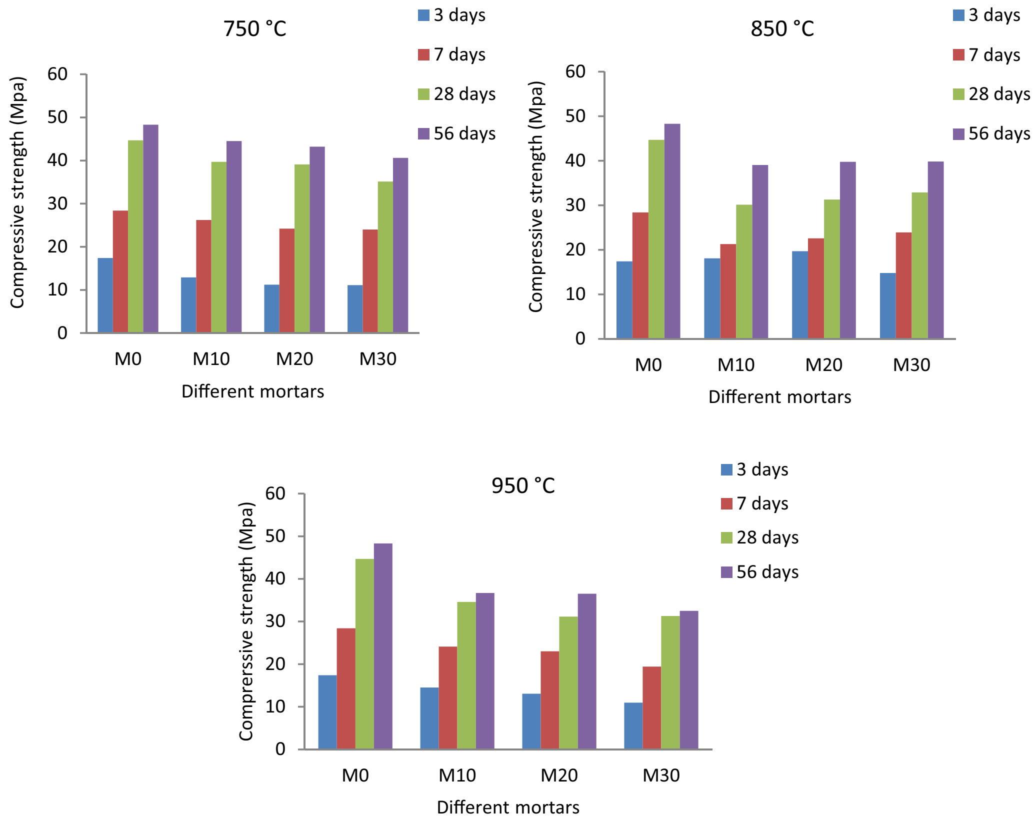

Fig. 9. Effect of calcined mud on the compressive strength of mortars.
M0, M10, M20 and M30 are mortars with 0, 10, 20 and 30% of mud, respectively.

3.3.3. Correlation between the compressive strength and flexural strength

The following power-law type relationship relates, through traditional empirical approach, the tensile strength to the compressive strength [37,38] (Fig. 11):

$$R_{t=}KR_c^a \tag{3}$$

where:

R_t is the tensile strength, R_c the compressive strength, K and a are constant coefficients.

The correlation obtained between the two strengths (compression and flexure) of standard curing in water at 20 °C is:

$$R_t = 0.421R_c^{0.737} \tag{4}$$

With a correlation coefficient $R^2 = 0.991$, mortars containing mud behave just like the reference mortar (control mortar).

4. Conclusion

The idea is to use calcined mud (of pozzolanic character) as a partial replacement in Portland cement which releases lime upon hydration. This would allow obtaining binders with characteristics similar to, or even better than, those of natural Portland cement (without additions). The research works presented in this article are within the general framework of the fight against the silting of dams in Algeria. Our contribution is mainly focused on opportunities for reuse in the dredged sediment industry. These natural wastes are here considered as potential mineral raw materials. The applicability of this mud on an industrial scale only depends on the study of the availability and sustainability of the raw material. The valorization of the mud from Fergoug dam has two objectives:

- On the one hand, it contributes to reducing the impact on the environment, whether the polluting effect of dredged sediments or the pollution due to the production of cement which releases very intense greenhouse gases,
- On the other hand, it allows recovering the dredging financial costs, through the use of mud in the composition of cement.

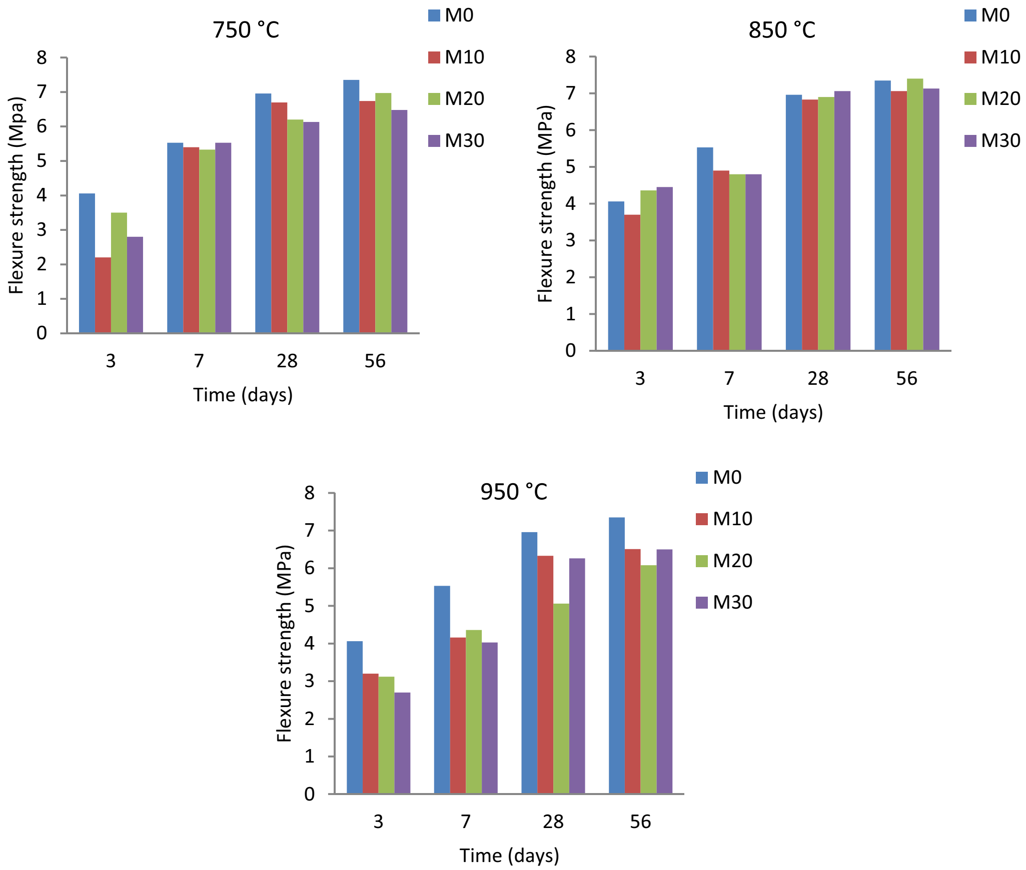

Fig. 10. Flexural strength of mortars with mud calcined at 750, 850 and 950 °C.

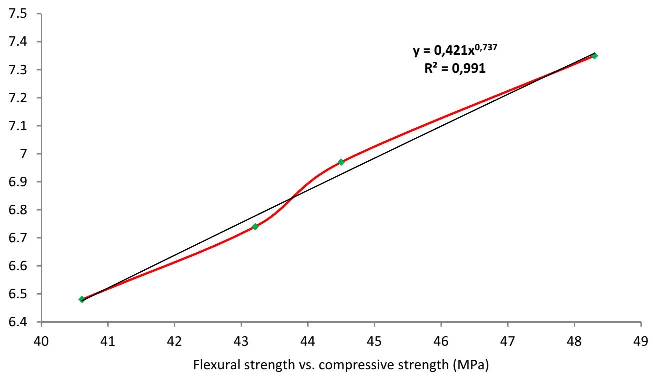

Fig. 11. Correlation between the compressive strength and the flexural strength, after 56 days.

The present study led to a number of results:

- The physical and chemical characterization of mud that went through heat treatment proved to be suitable as a pozzolanic material,
- Chemical composition test concluded that the mud samples, calcined at 850 and 950 °C, have values of the sum of the three main oxides close to the limit value of 70%, and hence the mud can be active at these temperatures.
- The results of the flow table test, in accordance with standard ASTM C 1437-01, show that mortar prepared with Portland cement, without any addition, has lower maneuverability than that made with calcined mud, when the amount of water

used is kept constant. Thus, the workability of mud mortars increases as the percentage of replacement of cement by mud rises, for all temperatures.
- For the setting time test, the results clearly indicate a proportional increase in the initial and final setting times with the rise in the substitution rate of cement by calcined mud.
- The mechanical strengths of mortars containing mud, calcined at the three temperatures, are better than that of reference (control) mortar formulated with CEM I. However mortars formulated with mud calcined at the temperature of 750 °C/3 h showed better mechanical performance than those obtained at 850 and 950 °C/3 h. It is the calcination of the mud at a temperature of 750 °C which yields the greatest compressive strengths of mortars to 10, 20 and 30% of silt at the age of 56 days. At this calcination temperature of (750 °C), it is the mortar M10 with the mortar M20 which give the best compressive strengths of mortars containing artificial pozzolan. The calcination temperature of 850 °C gave values of compressive strengths better than the calcination temperature of 950 °C but values lower than the calcination temperature of 950 °C at the age of 56 days. For the calcination temperature (850 °C), it is the mortar M20 which gives the best compressive strengths of mortars containing artificial pozzolan. The calcination temperature (850 °C) the compressive strength values (56 days) of mortars containing artificial pozzolan remain weaker than the normal mortar M0. Of all calcination temperatures, the calcination temperature at 950 °C gave the lowest compressive strengths and this, practically for all ages studied that is to say, 3, 7, 28 and 56 days.
- For the flexure strengths, it can be stated that in general the incorporation of calcined mud helps in improving the flexural strengths, at all substitution rates.
- X-ray diffraction tests were conducted on the raw and activated silt dredged at 750, 850 and 950 °C. The intensity of kaolinite peaks in the raw silt is very strong, and the related pattern indicates the good quality of this material and the existence of weak amounts of impurities. In addition, the microscopic analysis (XRD) allowed to see homogeneous shapes and confirmed the pozzolanic nature of the constituents of sediments from Fergoug dam.
- The thermal analysis DTA/TGA confirmed the metastable and crystalline states of sediments. The pozzolanic effect of calcined mud was confirmed by the appearance of a non-crystalline phase detected by the DTA curves. This helped to determine the optimum burning temperature that gives an artificial pozzolanic material that can be utilized in manufacturing mortars and concretes for the field of civil engineering. The temperature range for the amorphization of mud from Fergoug dam was found between 650 and 900 °C.

Finally, it can be said that the addition of mud, dredged from Fergoug dam, can give pozzolanic cement; this helps to save significant amounts of energy.

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