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Characterization of dredged sediments for a reuse as sand in mortars

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ABSTRACT
Dredged sediments cause serious problems for managers of the port of Oran due to lack of storage areas on land, so the solution chosen is a dumping at sea. The present study is based on the characterization of sediments collected from different docks of the port of Oran. Results obtained have allowed delineating two areas of contamination. Contaminated sediments are dangerous wastes. For sediments contaminated with organic and inorganic pollutants, the chemical treatment with a phosphate is proposed for a reuse as sand in mortars. The results led to the conclusion of the technical feasibility of this solution.

Introduction

The sediment accumulation in docks harbour is the natural phenomenon, so the dredging of marine sediments is necessary. Also, the shortage of natural aggregates and the increasing demand by the construction industry have encouraged research of alternative sources. These new sources of materials can be the sea sediments. However, dredged sediments (DS) contain amounts of marine water, and can contain the organic matter and heavy metals. Strategies for the beneficial reuse of waste were developed and have involved several fields of civil engineering such as mortars and concretes. Recent researches were carried out with untreated sediments. Ben Allal et al. [1] studied the sediments collected in the ports of Tangier and Larache (Morocco) and Limeira et al. [2] those extracted from the Port of Sant Carles de la Rápita (Tarragona, Spain).

Previous researches on the use of treated dredged marine sediments in mortars were carried out by Millrath et al. and Kozlova et al. [3, 4] with dredged marine sediments from ports of New Work and New Jersey (USA) and by Agostini et al. [5] with sediments from Dunkirk Harbour (France). All of the studies have shown that dredged sediments can be used but the results of the partial replacement percentage of sand by sediments aren't the same.

This work is a continuation of our previous works carried out in 2011 [6], 2012 [7] and 2013 [8a and 8b]. The DS were extracted from the Port of Oran, inside and outside different basins, stored in laboratory and submitted to sampling in order to determine their different properties. This is necessary in order to establish their identity card based on their physical, chemical and mineralogical characterisation [9]. Physical, chemical and mineralogy characteristics of DS were determined. After this complete characterization, DS must be treated differently; those extracted from area1 that are polluted by both heavy metals and by hydrocarbons will be submitted to chemical treatments [3, 4 and 5] and were treated by leaching and dewatering.

DS from the area 2 that were less contaminated by heavy metals and DS from the area1 were treated only by leaching and dewatering in order to reduce salts and water contents. They were then used in partial replacement of sand (20%, 25%, 30% and 35% by sand mass) in the making of different series of mortars. Rheological properties of the fresh mortar and physical properties of the hardened mortar were measured and compressive strengths of all series of mortar specimens were determined after 7, 28, 60 and 90 days of the moist curing. Test results were compared to those of the reference mortar.

Materials and methods

Materials

Characterization of dredged sediments

Samples of dredged sediments were collected from the port of Oran geographical location and the locations of sampling stations are given in "Fig.1" and "Fig.2" respectively.

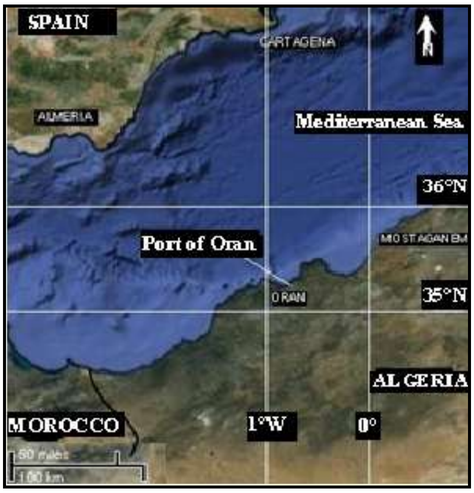

Figure 1. Geographical situation of the port of Oran

The chemical characterisation of minor elements is given in table1; these results were obtained by LEM and CDR [10]. The test results carried out by Draoui et al. [11] have shown that the average contents of total hydrocarbons (THC) contained in dredged sediments were 1000mg/kg outside basins and 2000mg/kg inside basins.

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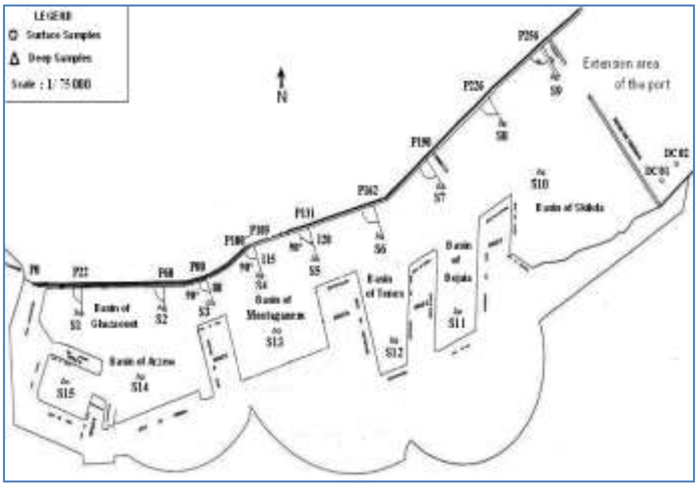


Figure 2. The port of Oran with the different basins

The Algerian Ministry of Physical Planning and Environment (MATE, 1999) [12] has definite pollution thresholds (Recommended Limits) from which sediments cannot be dumped at sea. So we are definite two contamination areas:

In Area 1 outside basins (stations S1 to S9): dredged sediments were contaminated by heavy metals and by hydrocarbons.

In Area 2 inside basins (stations S10 to S14): dredged sediments were found to be not contaminated by heavy metals but high quantities of hydrocarbons were detected.

Table 1. Average Contamination of chemical minor elements of dredged sediments

Pollutants mg/kg of dry sediments	Recommended Limits*	Different Basins	
		Average Value measured Outside Basins	Average Value measured Inside Basins
Cadmium (Cd)	3	0.08	0,16
Chromium (Cr)	250	34.16	118.3
Mercury (Hg)	1.5	1.64	1.02
Nickel (Ni)	75	342.5	9.6
Lead (Pb)	250	42.24	89.65
Zinc (Zn)	500	390.8	335.5
THC	300	1000	2000

*Recommended limits of the concentration of pollutants by “[12]”; THC: Total Hydrocarbons

All tests were performed on six samples of DS from the same batch. The chemical characteristics of major elements of DS were determined according to European standard 1744 (1998) [13]; the average values are reported in Table 2. According to European standard EN 206-1 (2002) [14] the chloride content in cement based materials of all components should not exceed 0.06% of aggregates weight and 0.4% of a cement weight.

Chlorides affect the kinetics of the hydration cement. The value in this study was about 1.6% inside basins and 1.7% outside basins; they exceeded limits and were high for a use of DS in cement based materials. Also sulphates can disrupt the hardening, hence the need to limit their content. Results of the sulphate concentration (see, Table 2) in DS samples from the Port of Oran showed an insignificant content.

Additional chemical characteristics and physical characteristics were also determined; the average values being given in Table 3.

Table 2. Average compositions (%) of the chemical major elements of dredged sediments

Chemical major elements (%)	Different Basins	
	Mean Value measured Outside Basins	Mean Value measured Inside Basins
SiO_2	45,0	54,5
CaO	25,0	19,0
Al_2O_3	4,1	4,3
Fe_2O_3	0,5	0,4
MgO	0,3	0,3
CL^-	1,7	1,6
SO_4	0,01	0,02
CO_2	20,0	15,2
H_2O	5,5	6,6

Table 3. Physical and chemical characteristics of DS

Tests	w (%)	ρ_s (kg/m^3)	SSB (m²/kg)	OM (%)	LI (%)
Measured value	63,5	2450	299	8,1	24,7
Tests	MB	pH	Carbonates (%)		EC (dS/m)
Measured value	0,9	8,8	40,5		4,8

Note: SSB Specific Surface Blaine; LI Loss on ignition; EC: Electrical Conductivity

According to the Algerian standard NA 451 (2006) [15], the measured initial water content was about 63.5%. This water content of DS corresponds to a medium value compared to values typically given in scientific literature that were about 150% to 200% [16].

The measured value of the density (ρ_s) was about 2450 kg/m^3 according to the Algerian standard NA 2595 (2006) [17], and was lower than the value adopted for local materials in general and for sand used in this study (2640 kg/m^3). This difference is due mainly to the presence of organic matter [18, 19].

The organic matter content (OM) of sediments was measured according to the Algerian test standard NA 461 (2005) [20]. According to these results and the European standard P 94 011 (1999) [21], the sediments can be considered as slightly organic. The activity of the clay fraction measured with the blue methylene test (MB) according the Algerian standard NA 1948 (2006) [22] is low, which confirms the clean character of DS.

The measured pH value of DS was about 8.8; this alkalinity can be linked to the presence of carbonates whose measured value according the European standard P 94-048 (1996) [23] was about 40.5%. The soil electrical conductivity (EC) is an indication of the levels of soluble salts in the soil. The measured E.C. value was about 4.82dS/m, according to the classification of Richards [24], DS were very salted. The particle size distribution of DS was determined using dry sieving according to European standard P 94-056 (1996) [25], and sedimentation according to European standard P 94-057 (1992) [26]. The average particle size distribution curves were given in “Fig.3”, showing that sediment DS are silt sands. The mineralogical analysis of sediments DS was carried out starting from the qualitative analyses by XRD; these highlighted the presence of crystalline phases, primarily of silica (SiO_2) and calcite ($CaCO_3$).

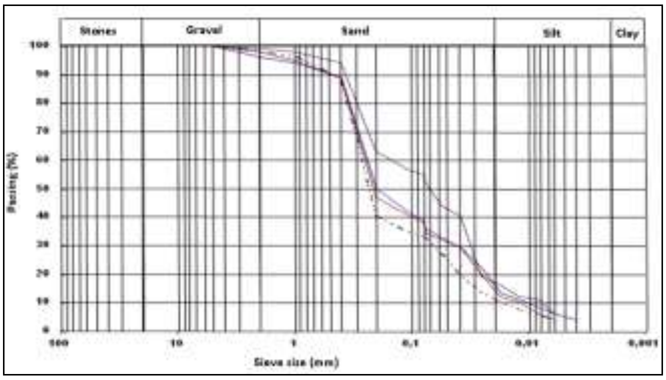


Figure 3. The average particle size distribution curves of DS

Methodology of reuse DS

Leaching and dewatering

All specimens (areas 1 and 2) are submitted of this treatment. Sediments DS have marine water content too high due to the degree of salinity, these values were greater than those allowed for use in cement based materials. The negative effect of salinity on mechanical strength development of cement based materials has been described by several authors [27, 28]. In order to use marine sediments in cement based materials, these have to undergo treatments necessary to decrease salinity. A soil leaching method [24] and natural decantation were considered economic methods to reduce the initial water content and salts of marine sediments. After 23 days of treatment, the water content of sediments DS decreased to, a low value equal to about 7%. After this treatment, the chemical analysis was carried out (Table 4). We note a decrease of the amount of chlorides and sulphates.

Table 4. Average compositions (%) of the major chemical elements of DS after leaching and dewatering

Chemical major elements (%)	Different Basins	
	Average Value measured Outside Basins	Average Value measured Inside Basins
SiO_2	45,0	54,5
CaO	25,0	19,0
Al_2O_3	4,1	4,3
Fe_2O_3	0,5	0,4
MgO	0,3	0,3
CL^-	0,0	0,0
SO_4	0,0	0,0
CO_2	20,0	15,2
H_2O	5,5	6,6

Chemical treatment of DS in area 1

The sediments collected in this area were submitted at chemical treatment. After the leaching and dewatering, they were then dried in air and in oven at 40°C. Then they have been chemically treated with phosphate (adding 3% phosphoric acid by mass of DS). Determining the percentage of phosphoric acid is carried out in the laboratory on different samples. Finally they have matured and dried for three (03) days. This treatment allows the trapping of heavy metals.

Components of reference mortar

Mortar is a mixture of cement, sand and water. Cement used is a blended Portland cement (Algerian standard, type II/A 42.5), produced by cement factory of Sig (West Algeria). Tables 5 and 6 show its chemical and mineralogical compositions and its physical characteristics respectively.

Table 5. Chemical and mineralogical compositions of cement

Components	Ratio (%)	Mineral phases	Ratio (%)
SiO_2	20,39	C_3S*	60,04
CaO	64,13	C_2S*	12,54
Al_2O_3	5,96	C_3A*	9,25
Fe_2O_3	3,57	C_4AF*	11,02
MgO	1,13	CaO free	0,35
SO_3	2,57	Gypsum	4
L.I	2,37		

Note: LI Loss on ignition; * Notations used in cement industry.

Table 6. Physical characteristics of cement and cement paste

Designation	Characteristics	Value
Cement	Cement Density (kg/m^3)	3100
	Specific surface (m²/kg)	391,8
Cement Paste	Normalised consistence (%)	24,5
	Initial setting time	2h 40mn
	Final setting time	4h

The sand used is calcareous crushed 0/4 mm sand from the Kristel quarry (East Oran). The correction of the particle size of the coarse sand was carried out by siliceous fine sand from Terga (West Oran), to obtain a grain size distribution curve within the standardised range. The physical characteristics of the quarry sand (after correction) are given in table 7. Water used is the drinking water distributed by the network of the public service.

Table 7. Physical characteristics of Kristel quarry sand

Physical characteristics		Values
Density (g/cm^3)		2.64
Sand equivalent	**Visual (%)**	79
	Piston (%)	70
Fineness modulus		2.25
Methylene blue value		1.28
Nature		Silico-calcareous

Methods

The aim of the study is to highlight the influence of partial substitution of sand by the chemically treated and untreated DS on the mechanical behaviour of mortars.

The mortars were produced in a 5-liter Hobart-type blender with two-speed capacity according the American standard ASTM C 305 [29], at a room temperature of 20 ± 2 °C with different mass fractions of sediment DS: 0% (this is the reference mortar RM), 20%, 25%, 30% and 35%, (These are the MS20, MS25, MS30, MS35 and MSP20, MSP25, MSP30, MSP35). The flow test is performed following the American standard ASTM C 1437 (2001) [30]. A cone-shaped mould is used to give the initial shape of the specimen. The mould is removed and the vibrating table is dropped 25 times in 15 seconds. During the test, the mortar was spread to form a circular mass, and the diameter of the mass is measured and compared to the initial size.

Flow F is defined as $F = [(D_{25} – D_0)/ D_0 \times 100(\%)]$, where D_{25} is the diameter of the mortar after the 25th drop and D_0 is the initial diameter of the mortar. The increase in size is expressed as a percentage of the initial size; for most mortars the required flow is 110%. The flow test is repeated, using a fresh batch of mortar each time, until the desired flow is achieved. The quantity of water needed to achieve flow is recorded, and this mortar is then tested for compressive strength.

The cubic-shaped test specimens (50×50×50 mm^3) made it possible to measure the volume of the accessible water pores for all mortars using the procedure given in the American standard ASTM C642 [31]. The cube specimens were dried in an oven at a temperature of 105°C for 24 h. After removing the specimen from the oven, it was allowed to cool in dry air and it was weighed (measure M1). Then the specimen was immersed in water and boiled continuously for 5 h. It was taken out, cooled, the surface moisture was removed by a towel and then the saturated weight was measured (M2). Volume of the accessible water pores is the ratio of the difference between the weight of sample after boiling and the weight of oven-dry sample. Volume of the accessible pores to water or porosity to water (P) is then defined by the following relationship:

P% = [(M2-M1)/M2] x 100.

The prismatic-shaped test specimens (40×40×160 mm^3) were made according to the European standard EN 196-1 (1995) [32]. The mortar was poured, and, after 24 hours, on removal of the test specimens from the mould, they were subjected to moist curing at a temperature of 20°C ± 2°C, and then tested with apparatus IBERT Test to determine compressive strength.

Results and discussion

Fresh mortars

The compositions of the mortars and results of workability are given in Table 8. As described in studies "[3, 33]" the workability of mortars or concrete mixtures is dependent upon three conditions: the grain size of aggregates, the degree of drainage which occurs and the percentage of dredged sediment material introduced. In this study, it was observed a substantial reducing on the mortars fluidity with the DS volume increasing. A part of the free water necessary for cement hydration is absorbed by sediment DS because their high specific surface, this which affect the mix plasticity which influences both the workability of mortars. Also, the grain size distribution of DS increases the compactness of granular mix (Sand + DS). We note that for a constant flow of the value 110% it necessary to increase the water-cement ratio when the percentage of DS increases.

Table 8. Compositions and workability of various mortars

Materials and Characte-ristics / Designation of mortars	Cement (kg/m^3)	Sand (kg/m^3)	DS (kg/m^3)	Ratio W/C (%)	Worka-bility (%)
Reference Mortar (RM)	450	1350	0	0,50	110
Mortar MS20	450	1080	270	0,58	110
Mortar MS25	450	1012,5	337,5	0,60	110
Mortar MS30	450	945	405	0,65	110
Mortar MS35	450	877,5	472,5	0,70	110
Mortar MSP20	450	1080	270	0,57	110
Mortar MSP25	450	1012,5	337,5	0,61	110
Mortar MSP30	450	945	405	0,65	110
Mortar MSP35	450	877,5	472,5	0,70	110

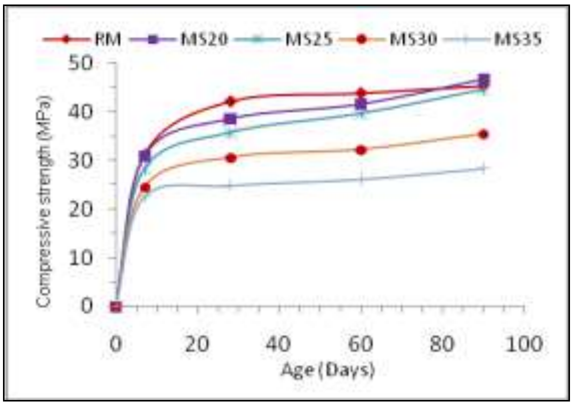
Hardened mortars

The mortar porosity has a great influence on the compressive strength Rc and the residual compressive strength Rcr. The results of measure the volume of the accessible water pores for all mortars have given 10.4% for mortar RM, 9.7% for MS20 and 9.5% for MSP20, 10.1% for MS25 and 10.0% for MSP25, 12.5% for MS30 and 12.1% for MSP30, 14.1% for MS35 and 14.0% for MSP35. The grain size distribution of DS allows the improvement of the compactness of granular mix (Sand + DS) to the value of 25%. In the mortars MS30, MSP30 and MS35, MSP35 the necessary amount of mixing water in order to obtain required workability in the fresh state, increased the volume of the accessible pores in set state.

The results given in table 9 concern the unconfined compressive strength (Rc), that were measured at 7, 28, 60 and 90days of moist curing. The evolution of the compressive strengths of all mortars is illustrated in Fig.4.

Table 9. Unconfined compressive strength Rc of mortars

Rc of mortars / Designation of mortars	Rc7 (MPa)	Rc28 (MPa)	Rc60 (MPa)	Rc90 (MPa)
RM	31,1	42,1	43,8	45,3
MS20	30,8	38,5	41,5	46,6
MS25	28,2	35,7	39,6	44,5
MS30	24,5	30,6	32,2	35,4
MS35	22,5	24,8	25,1	28,3
MSP20	30,1	38	39,5	44,9
MSP25	29,5	35,1	42	45,1
MSP30	26,7	32,7	38,5	34,5
MSP35	24,6	26,2	38,2	30,4



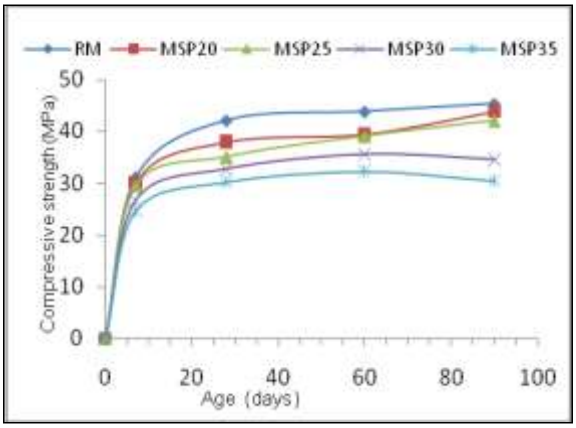


Figure 4. Curves of unconfined compressive strength Rc of mortars

It shows clearly that the general behaviour observed is in conformity with that of a mortar and those values of compressive strength of all mortars are lower than that of the RM mortar until the 60 days of aging. At the 90 day limit, we note that the compressive strengths of mortars MS20, MS25, MSP20 and MSP25 were almost equal to that of the RM mortar. At the 90 day limit, the negative effect of sediment DS is observed in the mortar MS30, MS35, MSP30 and MSP35 where the values of compressive strength of mortars are lower than the reference mortar RM with decrease of the value 21.8%, 37.5%, 24% and 33% respectively.

This reduction in compressive strength is due to the increase in the amount of mixing water in mortars that has increased the porosity of mortars MS30, MS35, MSP30 and MSP35. Similar results were found by "[2]".

Conclusions

The following conclusions are given on the basis of the results presented in this paper:

- The complete characterization of DS of the port of Oran has allowed determining two areas, the polluted zone by heavy metals and the unpolluted zone. For all specimens of DS, the methodology developed for the salts treatment and the dewatering of the DS is efficient in laboratory conditions. In polluted by heavy metals zone the additional chemical treatment was applied in DS.
- It was noted that to in order to obtain the same consistency, cements made with DS in partial substitution of raw sand needed more water than those made with coarse sand.
- The amount of mixing water needed in order to obtain required workability in fresh state increased the volume of the accessible pores in set state in the mortars MS30, MS35, MSP30 and MSP35.
- The unconfined compressive strengths in mortars MS20, MSP20, MS25 and MSP25 are similar to that mortar RM, but those of the mortars MS30, MS35, MSP30 and MSP35 are lower than to the mortar RM.
- Thus, we can conclude that the DS of the port of Oran can be substituted partially for the sand used in the manufacture of cement based materials. A percentage of 20% or 25% appears most suitable.
- Other tests are necessary to determinate if the chemical treatment is beneficial. The additional tests are the aptitude of the mortars to resist the acid attacks and to fire resistance.

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