Valorization of uncontaminated dredged marine sediment through sand substitution in marine grade concrete

Mahmoud Hayek, Tara Soleimani, Marie Salgues, Jean-Claude Souche, Eric Garcia-Diaz

Valorization of uncontaminated dredged marine sediment through sand substitution in marine grade concrete

Mahmoud Hayek[a*], Tara Soleimani[b], Marie Salgues[a], Jean Claude-Souche[a], Eric Garcia-Diaz[a]

[a] *LMGC, Univ Montpellier, IMT Mines Ales, CNRS, Ales, France*

[b] *HSM, Univ Montpellier, IMT Mines Ales, CNRS, IRD, Ales, France*

mahmoud.hayek@mines-ales.fr ; https://orcid.org/0000-0002-3164-2247

tara.soleimanij@gmail.com ; https://orcid.org/0000-0001-6101-6530

marie.salgues@mines-ales.fr ; https://orcid.org/0000-0002-8801-6730

jean-claude.souche@mines-ales.fr ; https://orcid.org/0000-0001-7923-9564

eric.garcia-diaz@mines-ales.fr ; https://orcid.org/0000-0003-4059-9145

Corresponding author:

Mahmoud Hayek

mahmoud.hayek@mines-ales.fr

LMGC, IMT Mines Ales, 6 avenue de Clavières, 30319, Alès, Cedex, France

Highlights

- Untreated fine sediments can be used as a substitute for sand in XS2 concrete
- Untreated fine marine sediments have a negative effect on concrete properties
- Up to 10% of sediment content resulted in comparable concrete properties
- Up to 30% of sediment content can be used after optimizing the concrete mix design

Abstract

Marine sediment disposal is an important economic and environmental issue worldwide. In order to minimize these discharges and optimize resources through a circular economy approach, this study discusses the potential use of fine marine sediments without treatments as a sand substitute in the marine concrete class (XS2, C30/37). The Dreux-Gorisse method was applied to find the concrete formulation containing 10, 20, 30, 40 and 50% sediment by weight. The results show that an XS2 concrete C30/37 with a water to binder ratio of 0.55 could be

designed with 10% of sediment replacement content without significantly affecting the concrete properties. However, the optimization of concrete mix design shows that marine concrete (XS2, C30/37) could be designed with 30% of sediment replacement content without significantly affecting the potential durability and the estimated lifetime of the concrete structure.

Keywords: dredged marine sediments, valorization, sand substitution, marine concrete, concrete properties, potential durability, estimated lifetime

1. Introduction

Concrete is the most widely used material in the world after water [1]. It is mainly composed of gravel, sand, binder and water [2]. Today, the large consumption of concrete is accompanied by rapid consumption of natural resources, and by a stricter requirement of environmental protocols. Therefore, making concrete in an environmentally friendly manner using alternative materials in the concrete manufacturing process becomes vitally important [3].

The production of one ton of Portland cement (CEM I) releases approximately one ton of carbon dioxide (CO_2). This energy-intensive production process involves significant resource consumption [4]. Therefore, several studies were carried out to find substitute materials that can be used as a partial replacement for CEM I. Then, the main identified supplementary cementitious materials (SCM) are ground granulated blast furnace slag (GGBS), fly ash, silica fume, metakaolin, and more recently marine sediments (treated in most cases) [5–10]. In recent years, the valorization of marine sediments as SCM in the production of concrete and self-compacting concrete has been widely studied [8,11–13]. For example, Safhi *et al.* showed that the use of 10% of treated marine sediment (dredged from Dunkirk harbor) as SCM in self-compacting concrete has no significant effect on fresh properties (workability and flowability) and the durability performance (chloride penetrability and external sulfate attack) of concrete specimens [11,14].

In addition to cement, the concrete industry uses a large amount of sand. Sand is the fine aggregate used in concrete manufacturing to ensure the granular continuity between the coarse aggregate and the cement [15]. Sand is generally obtained by extraction from land quarries or riverbeds. Because of the regulations and/or limited availability, the river deposit resources are becoming rare and expensive in some areas. On the other hand, crushing rocks to obtain the sandy fraction is difficult and requires high energy consumption [2]. In addition, sand is becoming scarce in some regions of the earth, and in some cases, the sand should be transported over long distances, which imposes negative economic and environmental impacts [16]. In contrast to the extensive SCM research, there is relatively limited experimental research on the feasibility of replacing crushed sand (CS) with an alternative material in concrete production. To date, two candidate materials have been mainly presented in the literature: dune sand and dredged marine sediments (DMS).

Dune sand (desert sand) could serve as an abundant alternative sand source in many countries. It is available from many sources around the world. The dune sand is composed of fine particles with spherical shapes and a finesse modulus (FM) close to 1. Research experiments show that dune sand can be used as a partial substitute for crushed sand in properly designed concrete mixes, without adverse effects [17–19].

Unlike the dune sand, the use of DMS as a partial replacement of CS in concrete production seems to be more complicated and difficult [20]. The rare research on the use of DMS as a partial substitution of CS in concrete or mortar manufacturing has shown mixed results. Elmoueden *et al*. studied the influence of partial substitution of sand by 15, 30 and 50% of dredged sediments in the production of air foam concretes. They found that sand replacement causes an increase in the compressive strength and density of concrete specimens [21]. Moradi and Shahnoori studied the effects of replacing sand with 15, 25, 35, 50 and 100% of DMS (dredged from the Persian Gulf) in the production of roller-compacted concrete. They found that the replacement of sand by DMS at a percentage smaller than 25% increases the compressive strength and decreases the water absorption and water permeability of concrete specimens. Contrariwise, high DMS percentage (>35%) decreases the mechanical properties of concrete specimens [22]. Ben Allal et *al*. showed that the use of 20% of raw sediments (collected from the ports of Tangier and Larache, Morocco) as a sand replacement leads to a 30% decrease in the compressive strength of mortar specimens [23]. However, for the proper use of DMS as a substitute for sand in concrete production, treatment is required [20]. In fact, DMS is mainly composed of water, fine particles, organic pollutants (tributyltin, polychlorinated biphenyls, polycyclic aromatic hydrocarbons…), inorganic pollutants (heavy metals: mercury, cadmium, arsenic, chromium…) and salts [6,10,20,24]. It is shown that the salts and the pollutants can affect the characteristics and the properties (cement hydration reaction, structural strength progress…) of concrete made with DMS [25].

Accordingly, to benefit from the large volume of marine sediments dredged annually (300 million m^3 for the whole of Europe and 300 million m^3 in the USA) [7], further research and studies are needed on the partial replacement of CS with dominantly fine-grained DMS. To the best of our knowledge, no information regarding the use of DMS as a partial substitute for CS in the manufacturing of marine concrete (XS2 environmental exposure conditions as defined in European Standard NF EN 206-1) [26] has been published. Therefore, the objective of this present study is to identify the possibility of using fine-grained dominated DMS as a CS substitute in marine concrete and to optimize the formulation, without engaging in polluting and expensive treatment processes. The long-term objective is to promote a circular economy approach by using fine untreated marine sediment (landfilled in most cases) as a partial replacement for sand in the production of concrete materials.

2. Materials and Methods

2.1. Experimental plan

In order to achieve the aims of this study, the procedure was planned in four main stages. 1) Physio-chemical characterization of DMS 2) Preparation of concrete specimens (water to binder ratio of 0.55) with 10, 20, 30, 40 and 50% of DMS as CS substitution, 3) Selection of substitution percentage, 4) optimization of the concrete formulation (Table 7).

The targeted concrete is a marine concrete (XS2) with a minimum compressive strength of 38 MPa (at 28 days, C30/37) and a slump of 190 mm ± 25 mm which gives a plastic concrete of class S4. According to NF EN 206-1, this concrete must be manufactured with water to binder ratio (w/b) of a maximum of 0.55.

In this paper, the Dreux-Gorisse method was applied to find the concrete formulation [27] and the obtained concrete was evaluated based on its workability, water porosity (water penetration under pressure), water absorption and compressive strength.

The substitution percentage selected in stage 3 is the highest percentage which:

- Requires no more than 2% of superplasticizer to achieve 180 mm ± 25 mm with slump test
- Gives a mechanical compressive resistance greater than 38 MPa at 28 days
- Does not significantly affect the water porosity (chosen as an indicator to assess the general quality of concrete)

The optimization of the concrete mix design was performed by adjusting the following parameters (Table 7):

- The quantity of mixing water (specimens with a w/b ratio of 0.55 and with an excess water of 10 L/m^3 and 20 L/m^3)

- The superplasticizer (SP2)
- The granular arrangement, by using a gravel 4/6.3 (g 4/6.3)
- The water to binder ratio (w/b = 0.50, w/b = 0.45)

2.2. Physio-chemical characterization of DMS

The DMS used in this study was obtained from Port-Camargue (Grau du Roi, France). The geographic locations of the dredging operation are shown in Figure 1. The dredged sediments from all the locations were mixed. The expected fraction of sediment was separated based on particle weight using hydrocyclone and dewatered by geotubes. Then, the collected samples from the geotubes were kept in hermetically sealed plastic bags and stored in the laboratory at 20°C until use. This sediment was not contaminated by heavy metals, polycyclic aromatic hydrocarbons, and Polychlorinated biphenyls (data not shown).

Figure 1. Geographic locations of dredging operation at port-Camargue (France) [28].

The particle size distribution of the DMS samples was determined using laser diffraction particle size analyzer (Beckman Coulter S13320) (Figure 2). The results show that the DMS has a mean and median diameter of 117.5 µm and 94.4 µm respectively. According to ISO 13320, this DMS contains 2.2% clay fraction (d < 2 µm), 36.3% fine fraction (2 µm < d < 63 µm), 48.7% fine sand (63 µ m< d < 200 µm) and 12.8% sand (200 µm < d < 2000 µm).

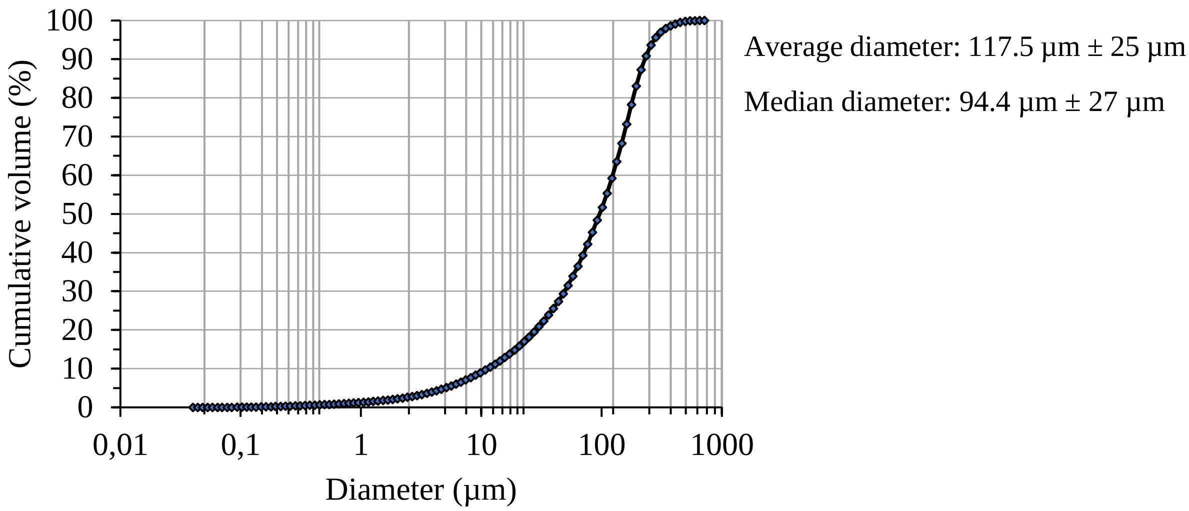


Figure 2. Particle size distribution of DMS used in this study. The results were obtained using laser particle size analysis according to ISO 13320.

The physical, mineralogical, and chemical characteristics of DMS used in this study are summarized in table 1. All experiments were performed in triplicate.

Table 1. Physical and mineralogical characteristics of DMS used in this study.

Material characteristic	Standard used	Measuring tool	DMS
Water content	NF P94-050	Oven at 105°C	17.7 ± 5.6
pH		pH meter	8.67 ± 0.13
Density (g/cm^3)	NF EN 1097-7	Micrometrics AccuPyc 1330 helium pycnometer	2.66 ± 0.01
Specific surface area (cm^2/g)	NF EN ISO 18757	Multipoint BET (Brunauer-Emmett-Teller) N2 adsorption	3.14 ± 0.82
Total organic carbon (%)	NF EN 13137	TOC-meter (Vario TOC cube)	2.69 ± 0.26
Blue methylene value (g/100g)	NF P94-068	Methylene blue solution	0.81 ± 0.45
Calcite (%)		Thermogravimetric analysis	10.8 ± 0.52
Major mineral elements (X-ray diffraction analysis)		D8 Advance diffractometer (Bruker)	Calcite ($CaCO_3$), Quartz (SiO_2) and Anhydrite ($CaSO_4$)
Morphology		Scanning electron microscopy (SEM)	Angular shape

Chemical composition (%)	DIN 51001	X-ray fluorescence	52.85 SiO_2 9.56 Al_2O_3 3.15 Fe_2O_3 0.37 TiO_2 3.30 K_2O 1.48 Na_2O 13.25 CaO 1.40 MgO 0.00 PbO 0.03 BaO 0.92 SO_3 0.07 MnO 0.10 P_2O_5 0.01 ZrO_2
		Ion chromatography	0.67 Cl^-

2.3. Materials used in the preparation of concrete specimens

2.3.1. Blended cement

In order to reduce the carbon footprint of concrete and to improve its durability in the marine environment [29,30], the blended cement used in this study is composed of 70% Portland cement 52.5 N and 30% Ground Granulated Blast-furnace Slag (Ecocem, France). It has been shown that the use of GGBS increases the durability of concrete against external aggression, including chloride penetration [31]. As specified in its technical data sheet, the reactivity index of this GGBS is 0.9. Its chemical composition is mentioned in table 2.

Table 2. Chemical composition (%) of Ground Granulated Blast-furnace Slag used in this study.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	SO_3	Cl^-	S^{2-}	Na_2O	K_2O
35.1	11.1	0.4	42.1	7.0	0.8	0.1	0.03	0.6	0.21	0.43

The cement used in this study, Portland cement 52,5 N - SR 5 CE PM-CP2 NF HTS (DURABAT® X-TREM) is specially formulated to resist sulfate and seawater (chloride) as stipulated in the technical data sheet. The characteristics of this cement are summarized in table 3.

Table 3 ; Characteristics of Portland cement 52,5 N used in this study. Min: Minute.

MgO	C3S	C2S	C3A	C4AF	Secondary constituents	Setting start time	Average of compressive strength at 28 days	True density
0.7%	66%	19%	4%	7%	3%	180 min	67 MPa	3.18 g/cm^3

2.3.2. Gravel

In this study, two types of crushed limestone were used, supplied by Languedoc Roussillon Matériaux (LRM). The grain size distributions of these gravel are shown in Figure 3. Gravel with size ranged from 6.3 to 14 mm (G) was used as coarse aggregate in all concrete specimens while gravel with size ranged from 4 to 6.3 mm (g) was used only during the third stage of the experimental plan (concrete formulation optimization). The characteristics of these two types of gravel are presented in Table 4.

Table 4. Characteristics of gravel used in this study.

Type	True density (Mg/m^3)	Water absorption (%)	Acid soluble sulfate (%)	Chloride (%)
Gravel 4-6.3	2.66	0.9	0.011	< 0.001
Gravel 6.3-14	2.63	0.7	0.05	< 0.001

2.3.3. Adjuvant and Superplasticizer

Two types of commercial superplasticizers (SP1 and SP2) were used in this study (Table 1). SP1 as the main SP applied in this study, is a new generation of superplasticizers based on a new technology of polymer synthesis. According to its technical data sheet, this SP maintains the workability of concretes for a long time without delaying the compressive strength development.

SP2 has been used to optimize the concrete formulation. It is recommended when CEM III is used in concrete manufacturing. This SP is compliant with concrete intended for contact with potable water (18 CLP LY 036).

Table 5. Properties of superplasticizers and adjuvant used in this study.

	Chemical composition	Density (g/cm^3)	Solid content (% wt)
Superplasticizer 1	Polycarboxylate	1.10	35.00
Superplasticizer 2	Polycarboxylate	1.07	31.00

2.3.4. Sand and sand-DMS mixes

The sand used in this study is calcareous crushed sand with sizes ranging from 0 to 4 mm (LRM). The sand-DMS mixes were obtained as follows:

1- Ambient Air drying of DMS for 48 hours: The water content decreases from 17.7 to 8% approximately

2- Mixing of DMS and CS according to the mass percentage (10, 20, 30, 40 or 50%) using a laboratory mortar mixer

3- The CS-DMS mixtures were kept in hermetically sealed plastic bags at 20°C until use

The grain size distribution of CS and CS-DMS mixtures used in this study are illustrated in Figure 3 and their fineness modulus (FM) (according to ASTM C33), true density and water absorption (WA) ratio (according to NF EN 1097-6) are given in Table 6.

Table 6. Fineness modulus, true density, and water absorption ratio of CS and CS-DMS mixtures used in this study. CS: Crushed sand. DMS: Dredged marine sediment. FM: Fineness modulus

	FM	True density (Mg/m^3)	Water absorption (%)
CS	3.23	2.62	1.40
CS + DMS 10%	2.78	2.55	2.40
CS + DMS 20%	2.37	2.47	3.20
CS + DMS 30%	2.18	2.39	4.10
CS + DMS 40%	1.95	2.32	5.30
CS + DMS 50%	1.70	2.25	6.90

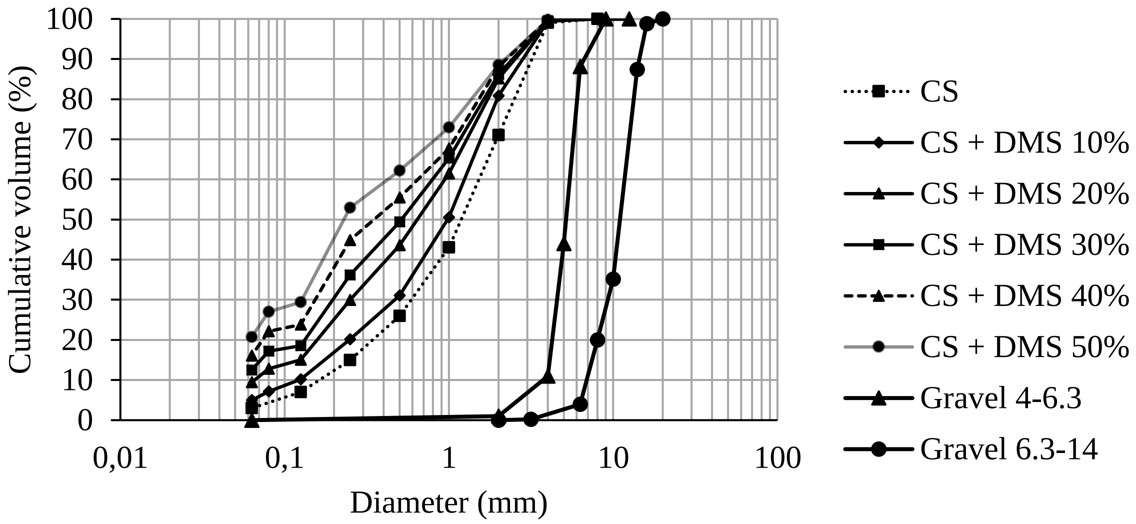


Figure 3. Particle size distributions of sand and gravels used in this study. CS: crushed sand. DMS: Dredged marine sediment.

2.4. Concrete mix design and specimen's preparation

In this study, the Dreux-Gorisse method was applied to find the concrete formulation [27]. Table 7 presents an overview of the investigated specimens, their composition, and their formulation properties.

Sample preparation was performed as follows. The solid contents, i.e., gravel, sand, binder and DMS are first introduced and mixed for 60 seconds (s). Then, water is progressively added. After 90 s, the superplasticizer is poured, and the constituents are mixed for 90 s.

After mixing, cylindrical specimens were cast in cylindrical cardboard molds of 110 mm diameter and 220 mm height and covered with a plastic lid. After 24 hours of hardening, the concrete specimens were removed from the molds and placed in water at 20°C for 28 days.

Table 7. Formulation properties and mixes design (Kg/m^3) of concrete specimens used in this study.

Concrete ID	0%	10%	20%	30%	40%	50%	30% + 10L	30% + 20L	30% + SP2	0% + g	30% + g	0% wb=0.5	30% wb=0.5	0% wb=0.45	30% wb=0.45
Gravel 6.3/14	785.5	835.5	882.0	901.5	927.5	951.0	901.5	901.5	901.5	570.6	570.6	584.1	584.1	597.6	597.6
Gravel 4/6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	292.7	312.6	299.6	319.9	306.5	327.3
CS	1059.5	894.2	736.8	614.6	503.4	400.0	614.6	614.6	614.6	1004.0	645.3	1027.8	660.5	1051.5	675.8
DMS	0.0	99.35	184.2	263.4	335.6	400.0	263.4	263.4	263.4	0.0	276.6	0.0	283.1	0.0	289.6
CEM1 52,5	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0	238.0
GGBS	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0
Effective w	181.5	181.5	181.5	181.5	181.5	181.5	181.5	181.5	181.5	181.5	181.5	165.0	165.0	148.5	148.5
w/b ratio	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.50	0.50	0.45	0.45
WC G (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WC g (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WC CS (%)	0.0	-	-	-	-	-	-	-	-	0.0	-	0.0	-	0.0	-
WC CS+DMS (%)	-	0.3	1.3	1.8	2.9	3.8	1.0	1.0	1.0	-	2.4	-	2.4	-	3.2
Mixing w	202.0	208.5	205.5	208.0	207.5	212.5	224.5	234.5	214.5	202.2	204.1	186.2	188.0	170.2	164.3
SP1 (%)	0.1	0.2	0.5	1.2	1.6	2.0	1.2	1.0	-	0.1	1.0	0.2	1.7	0.5	2.8
SP2 (%)	-	-	-	-	-	-	-	-	1.1	-	-	-	-	-	-
Paste volume (L)	307.3	321.6	337.2	347.6	359.1	373.6	347.6	347.6	347.6	306.1	347.9	289.8	332.5	273.4	317.1
Gravel/Sand	0.72	0.81	0.89	0.93	0.99	1.04	0.93	0.93	0.93	0.85	0.88	0.85	0.88	0.85	0.88

CS: crushed sand, DMS: Dredged marine sediment, GGBS: Ground Granulated Blast-furnace Slag, w: water, wb ratio: water to binder ratio

WC: water content, G: gravel 6.3/14, g: gravel 4/6.3, SP: superplasticizer, Mixing water = Effective water + WA of aggregates

2.5. Methods

2.5.1. Slump test

In order to analyze the effect of CS substitution by DMS on the properties of fresh concrete, the slump test was used after mixing concrete according to NF EN 12350-2 [32]. The targeted slump test after the addition of SP was 190 mm ± 25 mm which gives a plastic concrete of class S4. Then, the effect of DMS on the concrete workability was evaluated by the amount of SP added to achieve this targeted slump.

2.5.2. Mechanical compressive strength

The compressive strength tests (MPa) were carried out following NF EN 12390–3 standards [33]. A total of 3 specimens of each concrete type were tested at 28 days using compression testing machine (3R, France). The axial loading rate on each sample was 0.5 MPa/second.

2.5.3. Water porosity and water absorption

Water porosity and water absorption experiments were carried out at 28 days, following NF P18-459 [34] and NF EN 13369 [35] standards, respectively. Three samples (110 mm diameter and 50 mm height) of each concrete preparation were soaked in water for 48 h under pressure (vacuum saturation) and at atmospheric pressure (Water Absorption by Immersion, WAI) in the case of water porosity and water absorption respectively. The wet mass was measured after drying off each sample surface. For the dry mass, the samples were dried in an oven at 105°C to attain a constant weight with a tolerance of <0.05% of each sample weight.

2.5.3. Statistical analysis

To evaluate the significant effect of DMS on the concrete properties, statistical analysis was performed using one-way ANOVA tests on GraphPad Prism 5 (GraphPad Software, San Diego, CA, USA).

3. Results and discussion

3.1. Effect of DMS on concrete workability

Workability is one of the most important characteristics of fresh concrete. It is the main property that indicates the ability of concrete to be reshaped, moved and consolidated [36]. Figure 4 shows that the workability of concrete decreases with increasing DMS content. Consequently, the quantity of SP (% by binder weight) added to attain the targeted slump (190 mm ± 25 mm) increases when CS substitution by DMS increases. The SP requirement was 0.1% and 2.0% when the CS substitution by DMS was 0% and 50% respectively. These results are consistent with the study of Limeira et al [37]. In their study, Limeira *et al*. used additional plasticizer content when the sand was replaced by DMS in concrete mixes.

According to studies on concrete rheology, concrete workability is affected by many factors: (i) the amount and the type of binder, (ii) the Physico-chemical properties and the amount of fine and coarse aggregates, (iii) the amount and the type of chemical admixtures, (IV) water and the time and method of mixing … [38,39]. In this present study, the reduced workability of the concrete made with DMS can be justified by:

1. The angular shape and the rough surface of the DMS (Figure 5) [40]; According to [36], the angular fine aggregate particles interlock and reduce the freedom of movement of particles in the fresh concrete.
2. The number of fine particles (38.5%), the high specific surface area (3.14 cm^2/g, Table 1) and water absorption ratio of DMS and CS-DMS mixtures (Table 6) [41]; According to [42], the mixing water in concrete preparation exists in the forms of free layer water, adsorbed layer water and filling water. Among these forms of water, only the free layer of water contributes to concrete workability by separating solid particles. However, the amount of adsorbed layer water increases with the increase in surface area and the percentage of fine particles [3].

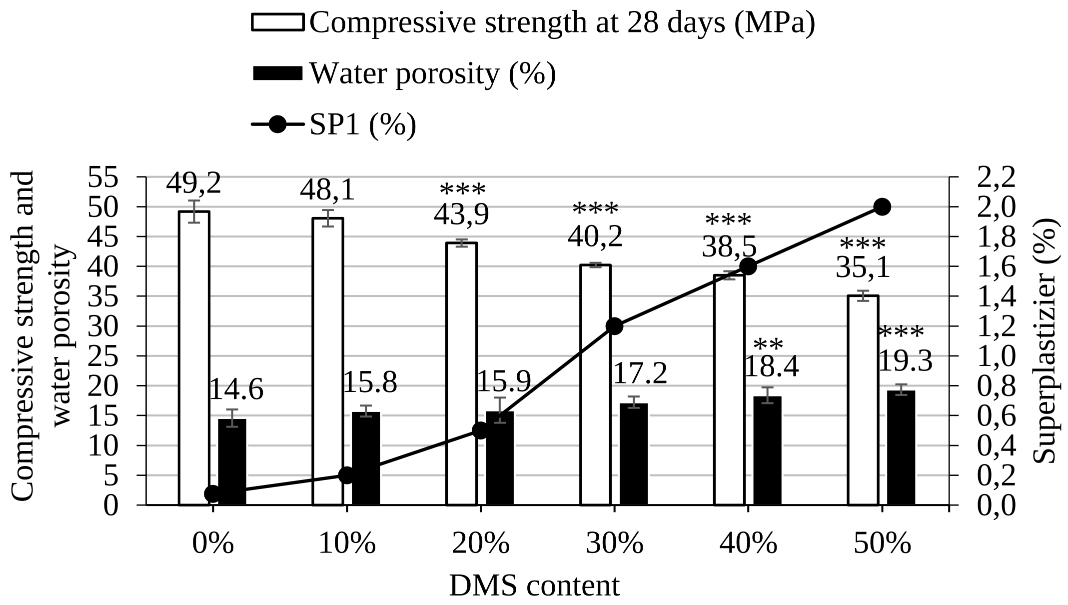


Figure 4. Effect of DMS on concrete workability, compressive strength, and water porosity). 0, 10, 20, 30, 40, and 50% present the substitution rate of crushed sand by dredged marine sediment. All experiments were performed in triplicate and the error

*bars present the standard deviation of the obtained values. The experiments highlighted with asterisks differed significantly from the control (Bonferroni; **: $p < 0.01$, ***: $p < 0.001$*

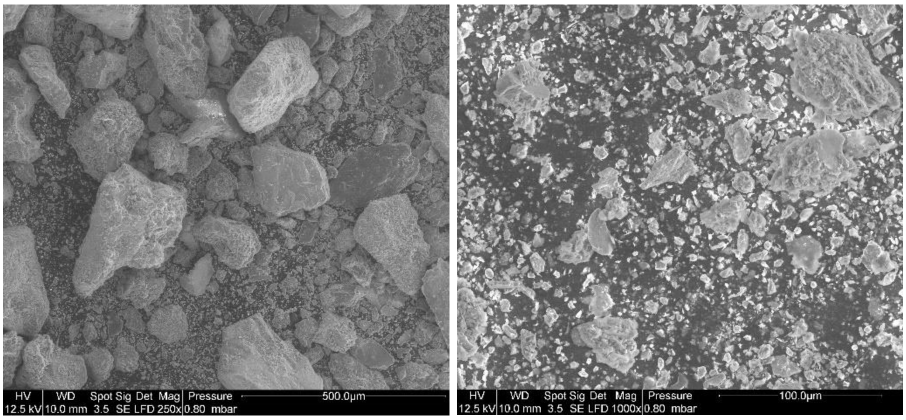


Figure 5. Scanning electron microscopy images of dredged marine sediment used in this study.

3.2. Effect of DMS on water porosity

In the marine environment, the water porosity of concrete is one of its most important characteristics, which strongly affects its mechanical behavior and service life [43]. Generally, an increase in concrete porosity leads to a reduction in compressive strength [44]. However, concrete porosity plays an important role with regard to the primary durability issues in seawater (external aggression, including chloride penetration) [45]. The effect of DMS on the water porosity of concrete specimens is shown in Figure 4. The results show that the water porosity increases with the increase of DMS content. The water porosity increases non-significantly from 14.6% to 17.2% when the substitution rate was 0% and 30% respectively. Then, the increase in water porosity becomes significant and reaches a value of 19.3% at a substitution rate of 50%. These results are in keeping with the study of [46] which showed that the porosity increases when the rate of sediment substitution increases. In this study, the increase in water porosity could be justified by the increase in the paste volume of concrete made with DMS (Table 7) and by the increase in the water absorption ratio of CS-DMS mixtures with an increasing substitution rate (Table 6).

3.3. Effect of DMS on mechanical resistance

The effect of DMS on the compressive strength of concrete is shown in Figure 4. The results indicate that the strength of concrete decreases with the increase in the proportion of DMS. At 10% of DMS content, the decrease in compressive strength (48.1 MPa) is not significant compared to the control (0%, 49.2 MPa). Contrariwise, using a substitution rate higher than

10% significantly affects the mechanical resistance of concrete specimens ($P_{value} < 0.001$). These results are in line with the study of Moradi and Shahnoori [22], in which the compressive strength of concrete specimens was negatively affected by the use of DMS content higher than 15%. However, based on the results of compressive strength analysis in this study, incorporating DMS as CS substitute in marine concrete at a rate lower than 50% is feasible, while retaining 38 MPa as the minimum compressive strength at 28 days.

The compressive strength of concrete is influenced by many factors including porosity, grain size distribution of aggregates, maximum size of aggregates, water to binder ratio, surface texture and strength [47]. As noted by Beddaa et al., 2020, the fine particles of sediments affect the properties of cement paste: because of to their specific surface area and water demand, fines and clay reduce workability and could also affect strength and durability. In this present study, the decrease in mechanical resistance may be attributed to (i) the effect of DMS on the pore's distribution and on the water porosity of concrete specimens (ii) the distribution (by DMS) of the organized granular arrangement formed by the conventional aggregates [48] (iii) the increase of the percentage of fine particles (<63 µm) in CS-DMS mixtures (Figure 3) and (IV) the chemical composition of DMS (i.e. salt content) (Table 1) [49,50].

3.4. Selection of substitution percentage

According to the slump, water porosity and compressive strength tests, a XS2 concrete C30/37 could be designed with 10% of sand replaced by DMS without significantly affecting the concrete properties. Therefore, DMS can be used as sand replacement in marine concrete manufacturing. However, a substitution rate of 30% is the highest DMS percentage that (i) required no more than 2% of SP to achieve the targeted slump, (ii) allowed a compressive strength higher than 38 MPa (38.5 MPa) and (iii) did not significantly affect the water porosity of concrete. Accordingly, the substitution rate of 30% was selected to optimize the concrete mix design using DMS as sand replacement. The objective was to minimize as much as possible the differences in the properties of the reference concrete and the concrete made with DMS.

3.5. Optimization of concrete mix design

The quantity of mixing water (+ 10 L/m^3, + 20 L/m^3), the superplasticizer (SP2), the granular arrangement and the water to binder ratio (w/b = 0.50, w/b = 0.45) are the parameters used to optimize the concrete mix design made with 30% of sand substitution by DMS.

The results of superplasticizer quantity, compressive strength at 28 days, water porosity and water absorption of the optimized concrete specimens are shown in Figure 6.

3.5.1. The quantity of mixing water

The quantity of mixing water is the first parameter to be optimized when the objective is to improve the durability of concrete. In this study we have used an excess quantity of water (+ 10 L/m^3, + 20 L/m^3) during the preparation of concrete made with CS-DMS to verify the calculation accuracy of water quantity added to concrete mixes according to the water absorption ration of CS-DMS (4.1%, Table 6). If the water absorption ratio of the CS-DMS is greater than the calculated ratio, the use of excess water does not influence the properties of hardened concrete. As shown in Figure 6, the compressive strength and the porosity of concrete specimens decrease and increase respectively with the increase of excess water. These results are in agreement with the technical sheet of Holcim Group [51] ; "each additional 10 liters of water per cubic meter will reduce the strength of concrete by about 2.5 MPa". These results confirm the accuracy of water mixing quantity used in the preparation of concrete specimens.

3.5.2. The superplasticizer

The fresh and hardened characteristics of concrete can be modified and controlled with superplasticizers [52]. However, the compatibility between the superplasticizer chosen and the cement used is a very important factor in concrete manufacturing. In the case of incorporation of mineral additions to Portland cement, several studies have been carried out to test the compatibility between superplasticizer and blended cement. The findings of these studies show that the effectiveness of superplasticizer is influenced by several factors such as the superplasticizer family, the mechanisms involved in superplasticizer action (electrostatic mechanism, steric obstacle…), the presence and the quantity of $Ca(OH)_2$ and the physio-chemical properties of Portland cement and minerals additives [53–56]. To the best of our knowledge, no information regarding the effectiveness of superplasticizer has been published when a DMS was used in concrete preparation. Therefore, in this study, a superplasticizer named SP2 was tested during the optimization of concrete mix design. Although SP2 belongs to the same family of SP1 (Polycarboxylate), the results show that SP2 (i) more effectively improves the concrete workability (Figure 6 A), (ii) improves the mechanical strength and the water porosity (compared to SP1) (Figure 6 B and C), (iii) gives the same water absorption compared to the control (5.9%) (Figure 6 D). Knowing the reasons of these differences will be the subject of a future study in our laboratory.

3.5.3. The granular arrangement

According to the literature, the aggregate used in concrete preparation affects the properties of fresh and hardened concrete [57]. Therefore, a gravel with size ranged from 4 to 6.3 mm was used in the optimization process to ensure the correct grain size distribution between the sand (0/4 mm) and the coarse gravel (6.3/14 mm). The results show that the use of gravel 4/6.3 mm improves the workability of concrete specimens in such a way that a smaller amount of SP was required to attain the targeted slump (190 mm ± 25 mm); the amount of SP added to attain the targeted slump is 1.2% and 1% (by cement weight) for the concrete without and with gravel 4/6.3 mm respectively. However, when the gravel 4/6.3 was used, (i) the compressive strength decreased slightly (2 and 0.2 MPa in the case of control concrete and concrete made with 30% DMS respectively), (ii) the water porosity increased slightly (0.8 and 0.7% in the case of control concrete and concrete made with 30% DMS respectively) and (iii) the water absorption increased slightly (0.5 and 0.8% in the case of control concrete and concrete made with 30% DMS respectively). Accordingly, the use of an intermediate gravel improves the fresh properties (the workability) and does not affect the hardened properties of concrete specimens. The slight differences observed at the hardened stat can be attributed to the characteristic differences between the gravel 4/6.3 and 6.3/14 (Table 4). Therefore, the intermediate gravel 4/6.3 was used in the concrete mix designs with w/b ratio of 0.50 and 0.45.

3.5.4. The water to binder ratio

In order to improve the durability of concrete, concrete specimens with a water to binder ratio of 0.50 and 0.45 were prepared. According to AFGC (French Association of Civil Engineering) the durability and the lifetime of marine concrete can be estimated according to the water porosity value and other durability indicators such as the permeability and the chloride diffusion coefficient [58]. Table 8 shows the potential durability and the estimated lifetime of marine concrete based on the porosity value. Therefore, according to AFGC, the concrete specimens prepared with a water to binder ratio of 0.55 (w/b =0.55, SP2, and +g 4/6.3) have a very low and a low potential durability in the case of control concrete (0%) and concrete made with 30% DMS respectively (Figure 6 C).

Table 8. Potential durability and estimated lifetime of concrete structure according to the water porosity value (AFGC, 2004).

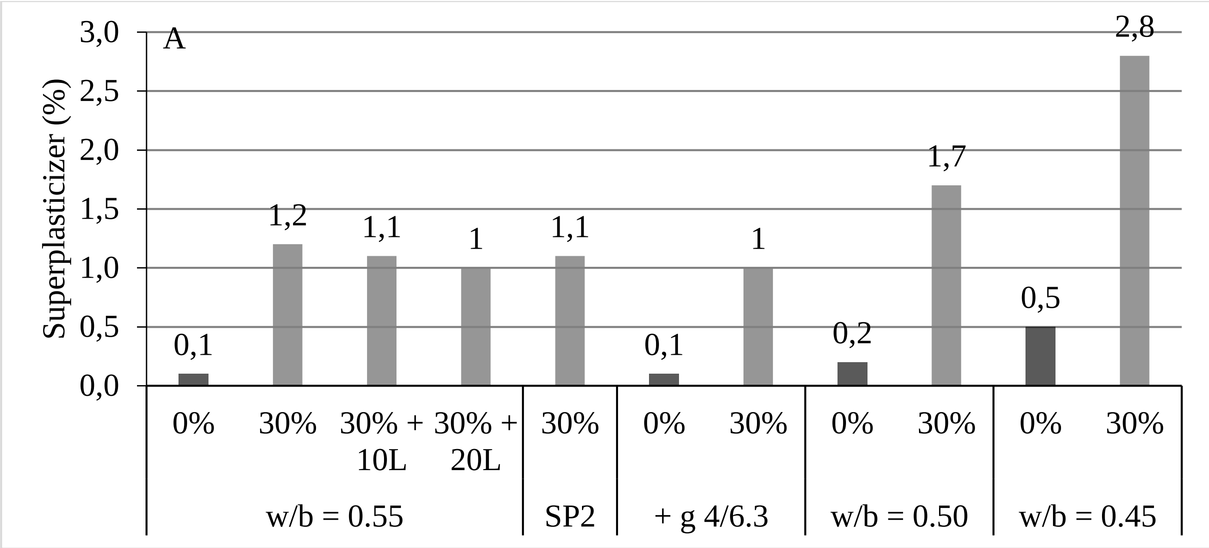
Water Porosity value (%)	16-15	15-14	14-12	12-9	<9
Potential durability	Very low	low	Medium	High	Very high
Estimated lifetime (years)	< 30	30-50	50-100	100-120	>120

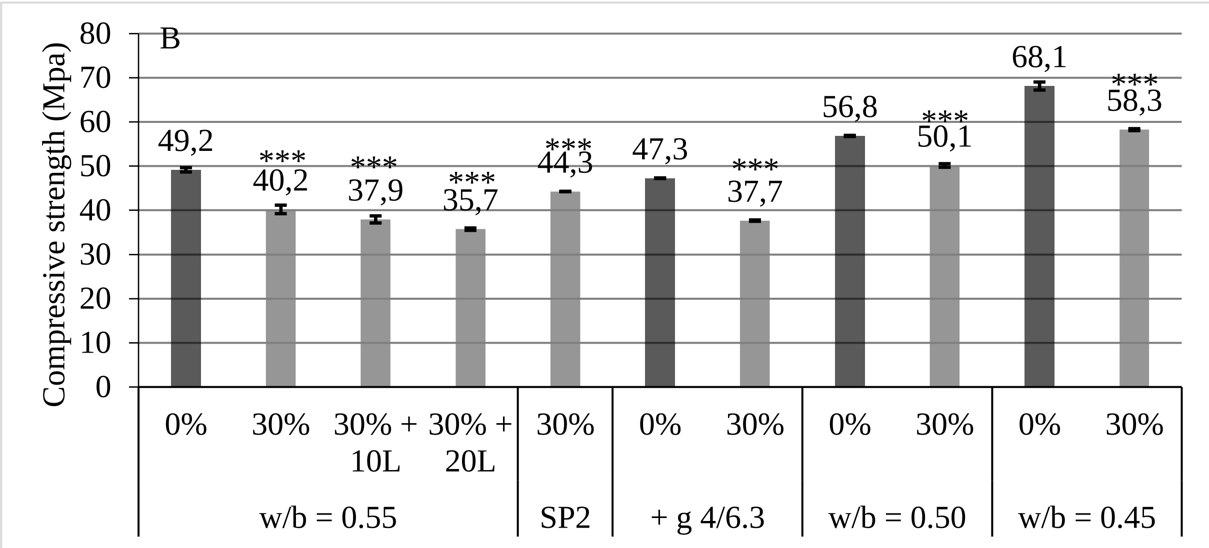
However, according to NF EN 206 [26], the water absorption value of marine concrete (XS2) must not be exceed 6%. Consequently, the water absorption ration of concrete specimens prepared with a water to binder ratio of 0.55 (w/b =0.55, SP2, and +g 4/6.3) does not meet the standard requirements (NF EN 206) (Figure 6 D).

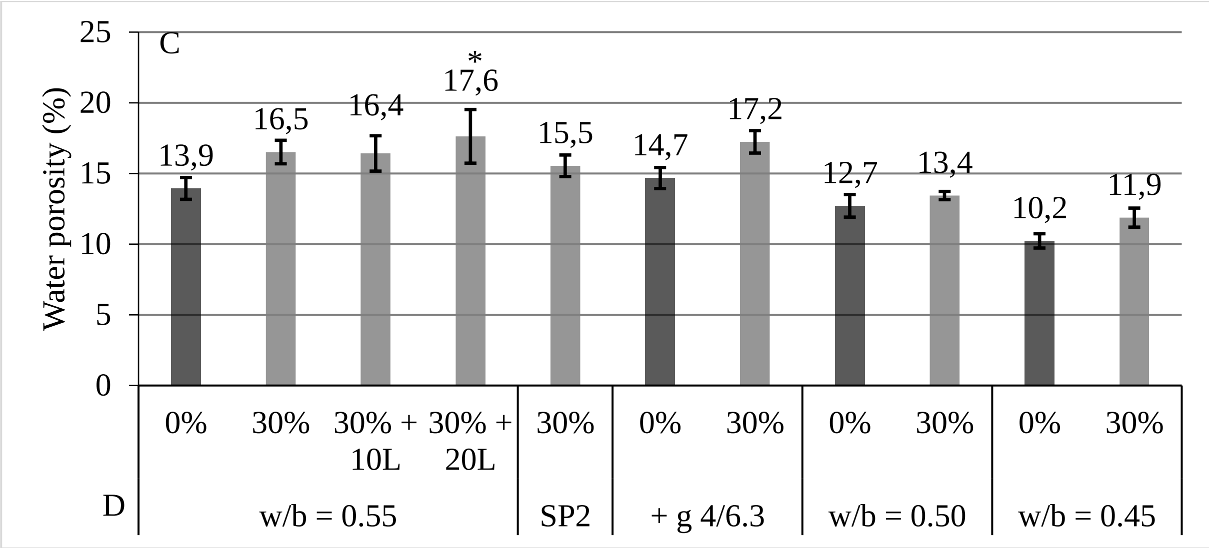
Therefore, reducing the w/b ratio is necessary to improve the potential durability and the estimated lifetime of concrete made with DMS. As expected, the results presented in Figure 6 show that the decrease of the w/b ratio has the following consequences:

- The quantity of SP (% by binder weight) required to attain the targeted slump (190 mm ± 25 mm) increases. In the case of w/b ratio of 0.45, the quantity of SP added is greater than 2% for the concrete made with DMS.
- The compressive strength increases
- The water porosity and water absorption decrease. The water absorption ratio is less than 6%.

However, according to the water porosity, the concrete specimens made with DMS (30% as sand substitution) have the same potential durability (medium and high for w/b ratio of 0.50 and 0.45 respectively) and the same estimated lifetime (between 50-100 years and between 100-120 years for w/b ratio of 0.50 and 0.45 respectively) as the concrete specimens made with CS. Thus, XS2 concrete C30/37 could be designed with 30% of sand replaced by DMS (which have the same physio-chemical properties of the DMS presented in this study) without significantly affecting the potential durability and the estimated lifetime of the concrete structure. Accordingly, in order to use the maximum rate of sand substitution by DMS in marine concrete without using an excessive amount of SP, the concrete specimens should be prepared with an intermediate gravel and a water to binder ratio of 0.5.


A
Superplasticizer (%)
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,1
1,2
1,1
1
1,1
0,1
1
0,2
1,7
0,5
2,8
0%
30%
30% + 10L
30% + 20L
30%
0%
30%
0%
30%
0%
30%
w/b = 0.55
SP2
+ g 4/6.3
w/b = 0.50
w/b = 0.45


B
Compressive strength (Mpa)
80
70
60
50
40
30
20
10
0
49,2
*** 40,2
*** 37,9
*** 35,7
*** 44,3
47,3
*** 37,7
56,8
*** 50,1
68,1
*** 58,3
0%
30%
30% + 10L
30% + 20L
30%
0%
30%
0%
30%
0%
30%
w/b = 0.55
SP2
+ g 4/6.3
w/b = 0.50
w/b = 0.45



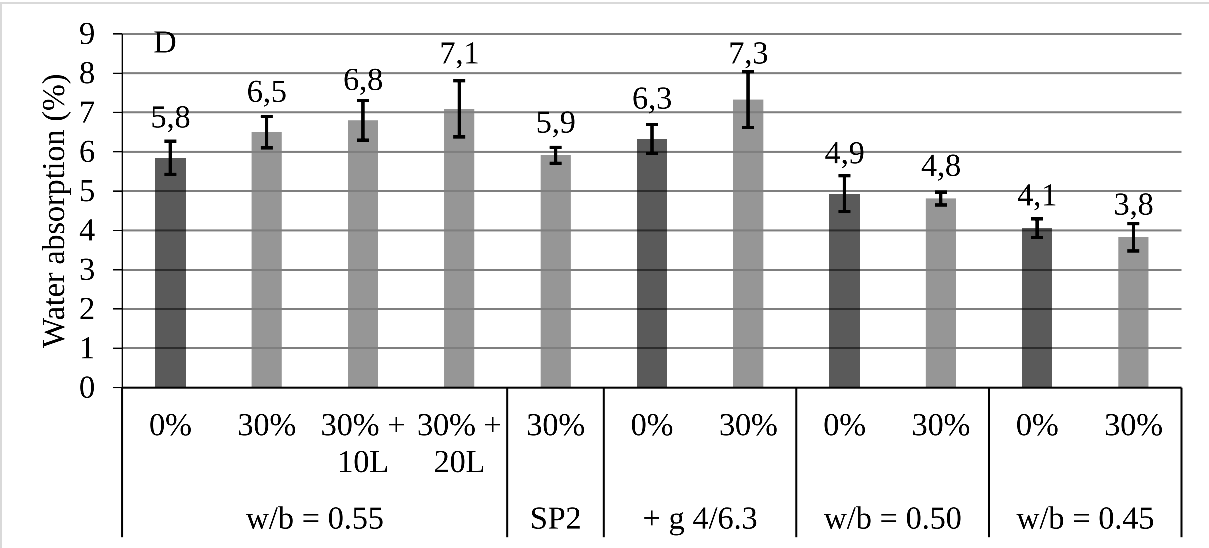


*Figure 6. Superplasticizer, Compressive strength at 28 days, water porosity and water absorption of concrete specimens prepared during the optimization of concrete mix design. All experiments were performed in triplicate and the error bars represent the standard deviation of the obtained values. The experiments highlighted with asterisks differed significantly from the control (Bonferroni; *: $p < 0.1$, ***: $p < 0.001$)*

4. Conclusions

With the large volume of marine sediments dredged annually and the ever-increasing demand for construction materials, the development of a new type of construction materials by using the dredged sediments would offer a global opportunity in terms of economy and environment. In this study, the effects of untreated marine sediments used as crushed sand replacement on the workability, compressive strength, water porosity and water absorption of concrete specimens were investigated. The following conclusions can be inferred from the results of this experimental study:

1. The partial substitution of crushed sand with dredged marine sediment (dominated by fine-grained sediment) affects the fresh properties of the concrete. The workability of concrete decreases with the increase of the substitution rate.
2. The compressive strength of concrete decreases significantly when the substitution rate exceeds10%.
3. The water porosity of concrete decreases significantly when the substitution rate exceeds 30%.
4. The quantity of mixing water, the chosen superplasticizer, the granular arrangement, and the water to binder ratio are conditions that should be optimized in order to produce a suitable concrete made with dredged marine sediment.
5. Based on the results of concrete mix design optimization, a marine concrete XS2, C30/37 could be designed with 30% of sand replacement by dredged marine sediment (which have the same physio-chemical properties of the DMS presented in this study) without significant impact on the potential durability and the estimated lifetime of concrete structure.

This paper presents a part of results of the ECODREGE MED II project. Based on the results obtained in this part of project, the designed and optimized concrete mix will be used for the following investigations:

1. Economic and environmental impact assessment of this new concrete made with DMS using life cycle assessment and life cycle cost assessment [59].
2. Investigating the rheological properties of concrete made with dredged marine sediment using mortar specimens.
3. Identifying the effects of replacing sand with 30% of marine sediment on the concrete durability parameters such as chloride diffusion, gas permeability…
4. Pilot implementation of a marine concrete structure through partial replacement of sand by dredged marine sediments, in collaboration with the concrete industry.

Author Contributions: Writing—review and editing, M.H., T.S., M.S., J.-C.S., and E.G.-D., All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the prefecture of the Occitanie Region (France) and European Union.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank the financial support of the Occitanie Region (France), the Prefecture of the Occitanie Region and European Union. The authors also thank IMT Mines Ales and University of Montpellier for their participation and support. The authors wish to acknowledge the help provided by Florian Stratta, Florent Lavorel, Thomas Wattez, Victor Beauvie and the internship students of the civil engineering department of Mines-Alès. The authors thank Ad-OCC, staffs of the ports of Camargue and Pérols particularly Yan Roux and Willy Paramé. The authors are grateful to Eurovia, DTE, LRM, HSM, Microbia Environnement and LIB Industry for their collaborative support.

References

[1] C.R. Gagg, Cement and concrete as an engineering material: An historic appraisal and case study analysis, Eng. Fail. Anal. 40 (2014) 114–140. https://doi.org/10.1016/j.engfailanal.2014.02.004.

[2] J. Kaufmann, Evaluation of the combination of desert sand and calcium sulfoaluminate cement for the production of concrete, Constr. Build. Mater. 243 (2020) 118281. https://doi.org/10.1016/J.CONBUILDMAT.2020.118281.

[3] F.J. Luo, L. He, Z. Pan, W.H. Duan, X.L. Zhao, F. Collins, Effect of very fine particles on workability and strength of concrete made with dune sand, Constr. Build. Mater. 47 (2013) 131–137. https://doi.org/10.1016/J.CONBUILDMAT.2013.05.005.

[4] A. Alhozaimy, A. Al-Negheimish, O.A. Alawad, M.S. Jaafar, J. Noorzaei, Binary and ternary effects of ground dune sand and blast furnace slag on the compressive strength of mortar, Cem. Concr. Compos. 34 (2012) 734–738. https://doi.org/10.1016/J.CEMCONCOMP.2012.03.002.

[5] M. Zdiri, N.E. Abriak, M. Ben Ouezdou, J. Neji, The use of fluvial and marine sediments in the formulation of Roller Compacted Concrete for use in pavements, Environ. Technol. 30 (2009) 809–815. https://doi.org/10.1080/09593330902990097.

[6] E. Rozière, M. Samara, A. Loukili, D. Damidot, Valorisation of sediments in self-consolidating concrete: Mix-design and microstructure, Constr. Build. Mater. 81 (2015) 1–10. https://doi.org/10.1016/j.conbuildmat.2015.01.080.

[7] M. Amar, M. Benzerzour, A. el M. Safhi, N.E. Abriak, Durability of a cementitious matrix based on treated sediments, Case Stud. Constr. Mater. 8 (2018) 258–276. https://doi.org/10.1016/j.cscm.2018.01.007.

[8] A. el M. Safhi, M. Benzerzour, P. Rivard, N.E. Abriak, Feasibility of using marine sediments in SCC pastes as supplementary cementitious materials, Powder Technol. 344 (2019) 730–740. https://doi.org/10.1016/j.powtec.2018.12.060.

[9] R. Achour, R. Zentar, N.E. Abriak, P. Rivard, P. Gregoire, Durability study of concrete incorporating dredged sediments, Case Stud. Constr. Mater. 11 (2019) e00244. https://doi.org/10.1016/j.cscm.2019.e00244.

[10] F. Agostini, F. Skoczylas, Z. Lafhaj, About a possible valorisation in cementitious materials of polluted sediments after treatment, Cem. Concr. Compos. 29 (2007) 270–278. https://doi.org/10.1016/j.cemconcomp.2006.11.012.

[11] A. el M. Safhi, P. Rivard, A. Yahia, K. Henri Khayat, N.E. Abriak, Durability and transport properties of SCC incorporating dredged sediments, Constr. Build. Mater. 288 (2021) 123116. https://doi.org/10.1016/j.conbuildmat.2021.123116.

[12] N.P. Ouédraogo, F. Becquart, M. Benzerzour, N.-E. Abriak, Environmental assessment, mechanical behavior, and chemical properties of self-compacting mortars (SCMs) with harbor dredged sediments to be used in construction, Environ. Sci. Pollut. Res. 28 (2021) 55003–55013. https://doi.org/10.1007/s11356-020-12279-6.

[13] H. Mehdizadeh, M.Z. Guo, T.C. Ling, Ultra-fine sediment of Changjiang estuary as binder replacement in self-compacting mortar: Rheological, hydration and hardened properties, J. Build. Eng. 44 (2021) 103251. https://doi.org/10.1016/j.jobe.2021.103251.

[14] A. el M. Safhi, M. Benzerzour, P. Rivard, N.E. Abriak, I. Ennahal, Development of self-compacting mortars based on treated marine sediments, J. Build. Eng. 22 (2019) 252–261. https://doi.org/10.1016/j.jobe.2018.12.024.

[15] L. Zeghichi, Z. Benghazi, L. Baali, The Effect of the Kind of Sands and Additions on the Mechanical Behaviour of S.C.C, Phys. Procedia. 55 (2014) 485–492. https://doi.org/10.1016/J.PHPRO.2014.07.070.

[16] P. Peduzzi, Sand, Rarer than One Thinks: UNEP Global Environmental Alert Service (GEAS) - March 2014, UNEP Rep. (2014). https://wedocs.unep.org/handle/20.500.11822/8665 (accessed July 7, 2022).

[17] E. Lee, J. Ko, J. Yoo, S. Park, J. Nam, Analysis of the Aggregate Effect on the Compressive Strength of Concrete Using Dune Sand, Appl. Sci. 2021, Vol. 11, Page

1952. 11 (2021) 1952. https://doi.org/10.3390/APP11041952.

[18] A.S. Al-Harthy, M.A. Halim, R. Taha, K.S. Al-Jabri, The properties of concrete made with fine dune sand, Constr. Build. Mater. 21 (2007) 1803–1808. https://doi.org/10.1016/j.conbuildmat.2006.05.053.

[19] M. Bédérina, M.M. Khenfer, R.M. Dheilly, M. Quéneudec, Reuse of local sand: effect of limestone filler proportion on the rheological and mechanical properties of different sand concretes, Cem. Concr. Res. 35 (2005) 1172–1179. https://doi.org/10.1016/J.CEMCONRES.2004.07.006.

[20] F. Kazi Aoual-Benslafa, D. Kerdal, B. Mekerta, A. Semcha, The Use of Dredged Sediments as Sand in the Mortars for Tunnel Lining and for Environmental Protection, Arab. J. Sci. Eng. 39 (2014) 2483–2493. https://doi.org/10.1007/s13369-013-0805-9.

[21] H. Elmoueden, M. Amar, A. Zambon, M. Benzerzour, N.-E. Abriak, The Use of Dredged Marine Sediment in the Formulation of Air–Foam Concrete, Waste and Biomass Valorization. 13 (2022) 2591–2607. https://doi.org/10.1007/s12649-021-01650-4.

[22] S. Moradi, S. Shahnoori, Eco-friendly mix for Roller-Compacted Concrete: Effects of Persian-Gulf-Dredged marine sand on durability and resistance parameters of concrete, Constr. Build. Mater. 281 (2021). https://doi.org/10.1016/j.conbuildmat.2021.122555.

[23] L. BEN Allal, M. Ammarri, I. Frar, A. Azmani, N.E. Belmokhtar, Caractérisation et valorisation des sédiments de dragage des ports de Tanger et Larache (Maroc), Rev. Paralia. 4 (2011) 5.1-5.13. https://doi.org/10.5150/REVUE-PARALIA.2011.005.

[24] Q. Wang, J. shan Li, Q. Xue, C.S. Poon, Immobilization and recycling of contaminated marine sediments in cement-based materials incorporating iron-biochar composites, J. Hazard. Mater. 435 (2022) 128971. https://doi.org/10.1016/j.jhazmat.2022.128971.

[25] M. Amar, M. Benzerzour, J. Kleib, N.E. Abriak, From dredged sediment to supplementary cementitious material: characterization, treatment, and reuse, Int. J. Sediment Res. 36 (2021) 92–109. https://doi.org/10.1016/j.ijsrc.2020.06.002.

[26] Concrete — Specification , performance , production and conformity, BSI Stand. (2016) 30. https://cobaz.afnor.org/notice/norme/nf-en-206-cn/FA185553?rechercheID=8821543&searchIndex=6&activeTab=all#id_lang_2_Titles (accessed August 26, 2022).

[27] C. Hamza, S. Bouchra, B. Mostapha, B. Mohamed, Formulation of Ordinary Concrete using the Dreux-Gorisse Method, Procedia Struct. Integr. 28 (2020) 430–439. https://doi.org/10.1016/J.PROSTR.2020.10.050.

[28] Grau-du-Roi : APP dragage du chenal sud de Port Camargue / Déclaration / Loi sur l'eau / Environnement / Publications / Accueil - Les services de l'État dans le Gard, (n.d.). https://www.gard.gouv.fr/Publications/Environnement/Loi-sur-l-eau/Declaration/Grau-du-Roi-APP-dragage-du-chenal-sud-de-Port-Camargue (accessed December 14, 2022).

[29] G. Li, A. Zhang, Z. Song, S. Liu, J. Zhang, Ground granulated blast furnace slag effect on the durability of ternary cementitious system exposed to combined attack of chloride and sulfate, Constr. Build. Mater. 158 (2018) 640–648. https://doi.org/10.1016/J.CONBUILDMAT.2017.10.062.

[30] H.W. Song, V. Saraswathy, Studies on the corrosion resistance of reinforced steel in concrete with ground granulated blast-furnace slag—An overview, J. Hazard. Mater. 138 (2006) 226–233. https://doi.org/10.1016/J.JHAZMAT.2006.07.022.

[31] N. Hosseinzadeh, L. Montanari, P. Suraneni, Durability of concretes exposed to high concentrations of CaCl2 and MgCl2, Mater. Struct. 2022 556. 55 (2022) 1–18. https://doi.org/10.1617/S11527-022-01992-Y.

[32] EN 12350-2, Testing fresh concrete - Part 2: Slump test, (2019) 10. https://cobaz.afnor.org/notice/norme/nf-en-12350-2/FA190558?rechercheID=8661844&searchIndex=1&activeTab=all (accessed August 17, 2022).

[33] EN 12390-3, Testing hardened concrete - Part 3: Compressive strength of test specimens, BSI Stand. Publ. 38 (2002). https://cobaz.afnor.org/notice/norme/nf-en-12390-3/FA190566?rechercheID=8661892&searchIndex=1&activeTab=all (accessed August 17, 2022).

[34] NFP18-459, Concrete - Testing hardened concrete - Testing porosity and density - Béton, in: 2010. https://cobaz.afnor.org/notice/norme/nf-p18-459/FA203045?rechercheID=8820380&searchIndex=1&activeTab=all#id_lang_2_Titles (accessed August 26, 2022).

[35] EN 13369, Common rules for precast concrete products, 2018. https://cobaz.afnor.org/notice/norme/nf-en-

13369/FA188565?rechercheID=8661977&searchIndex=1&activeTab=all#id_lang_2_Titles (accessed August 17, 2022).

[36] E.S.S.A. Seif, Assessing the engineering properties of concrete made with fine dune sands: An experimental study, Arab. J. Geosci. 6 (2013) 857–863. https://doi.org/10.1007/s12517-011-0376-6.

[37] J. Limeira, L. Agullo, M. Etxeberria, Dredged marine sand in concrete: An experimental section of a harbor pavement, Constr. Build. Mater. 24 (2010) 863–870. https://doi.org/10.1016/j.conbuildmat.2009.12.011.

[38] Q. Ren, Y. Tao, D. Jiao, G. De Schutter, Z. Jiang, Rheological properties of concrete with manufactured sand: A multi-level prediction, Cem. Concr. Compos. 133 (2022) 104647. https://doi.org/10.1016/J.CEMCONCOMP.2022.104647.

[39] FHWA, Federal Highway Administration, Portland-Cement Concrete Rheology and Workability: Final Report Publication No.RD-00-025, (2001).

[40] D. Benkeser, K. Hernandez, F. Lolli, K. Kurtis, Influence of calcined clay morphology on flow in blended cementitious systems, Cem. Concr. Res. 160 (2022) 106927. https://doi.org/10.1016/j.cemconres.2022.106927.

[41] M. Zhang, X. Zhu, J. Shi, B. Liu, Z. He, C. Liang, Utilization of desert sand in the production of sustainable cement-based materials: A critical review, Constr. Build. Mater. 327 (2022) 127014. https://doi.org/10.1016/J.CONBUILDMAT.2022.127014.

[42] A. Wang, C. Zhang, W. Sun, Fly ash effects: I. The morphological effect of fly ash, Cem. Concr. Res. 33 (2003) 2023–2029. https://doi.org/10.1016/S0008-8846(03)00217-5.

[43] S. Diamond, Aspects of concrete porosity revisited, Cem. Concr. Res. 29 (1999) 1181–1188. https://doi.org/10.1016/S0008-8846(99)00122-2.

[44] R. Kumar, B. Bhattacharjee, Porosity, pore size distribution and in situ strength of concrete, Cem. Concr. Res. 33 (2003) 155–164. https://doi.org/10.1016/S0008-8846(02)00942-0.

[45] B. Touil, F. Ghomari, A. Khelidj, S. Bonnet, O. Amiri, Durability assessment of the oldest concrete structure in the Mediterranean coastline: The Ghazaouet harbour, Mar. Struct. 81 (2022) 103121. https://doi.org/10.1016/j.marstruc.2021.103121.

[46] Z. Zhao, M. Benzerzour, N.E. Abriak, D. Damidot, L. Courard, D. Wang, Use of uncontaminated marine sediments in mortar and concrete by partial substitution of cement, Cem. Concr. Compos. 93 (2018) 155–162. https://doi.org/10.1016/j.cemconcomp.2018.07.010.

[47] A. Ghani, Z. Ali, F.A. Khan, S.R. Shah, S.W. Khan, M. Rashid, Experimental study on the behavior of waste marble powder as partial replacement of sand in concrete, SN Appl. Sci. 2 (2020) 1–13. https://doi.org/10.1007/S42452-020-03349-Y/FIGURES/15.

[48] H. Beddaa, I. Ouazi, A. Ben Fraj, F. Lavergne, J.M. Torrenti, Reuse potential of dredged river sediments in concrete: Effect of sediment variability, J. Clean. Prod. 265 (2020) 121665. https://doi.org/10.1016/J.JCLEPRO.2020.121665.

[49] B. Subashini, G. Sivaranjani, G. Dhanalakshmi, K. Gayathri, A.A. Kumar, A. Srimathi, C. Revathi, Experimental Investigation of Sea Sand for Construction Purposes, Indian J. Sci. Technol. 9 (2016) 1–5. https://doi.org/10.17485/ijst/2016/v9i11/89400.

[50] N.P. Ratnayake, U.G.A. Puswewala, S.P. Chaminda, E.M.T.M. Ekanayaka, A.M.N. Jayawardene, EVALUATION OF THE POTENTIAL OF SEA SAND AS AN ALTERNATIVE TO RIVER SAND FOR CONCRETE PRODUCTION IN SRI LANKA, J. Geol. Soc. Sri Lanka. 16 (2014) 109–117. https://www.researchgate.net/publication/274007763 (accessed August 23, 2022).

[51] Holcim Group, Excess Water In Concrete | Holcim Australia - Holcim Australia Pty Ltd, (n.d.). https://www.holcim.com.au/products-and-services/tools-faqs-and-resources/do-it-yourself-diy/excess-water-in-concrete (accessed August 25, 2022).

[52] O. Burgos-Montes, M. Palacios, P. Rivilla, F. Puertas, Compatibility between superplasticizer admixtures and cements with mineral additions, Constr. Build. Mater. 31 (2012) 300–309. https://doi.org/10.1016/J.CONBUILDMAT.2011.12.092.

[53] N. Mikanovic, C. Jolicoeur, Influence of superplasticizers on the rheology and stability of limestone and cement pastes, Cem. Concr. Res. 38 (2008) 907–919. https://doi.org/10.1016/j.cemconres.2008.01.015.

[54] H. Vikan, H. Justnes, F. Winnefeld, R. Figi, Correlating cement characteristics with rheology of paste, Cem. Concr. Res. 37 (2007) 1502–1511. https://doi.org/10.1016/J.CEMCONRES.2007.08.011.

[55] S. Han, P. Yan, X. Kong, Study on the compatibility of cement-superplasticizer system based on the amount of free solution, Sci. China Technol. Sci. 2011 541. 54 (2010) 183–189. https://doi.org/10.1007/S11431-010-4174-2.

[56] D. Sathyan, K.B. Anand, Influence of superplasticizer family on the durability characteristics of fly ash incorporated cement concrete, Constr. Build. Mater. 204 (2019) 864–874. https://doi.org/10.1016/J.CONBUILDMAT.2019.01.171.

[57] M.U. Nisa, Study to Find Out Shape Effect of Coarse Aggregate on Workability and Compressive Strength of Concrete, Int. J. Res. Appl. Sci. Eng. Technol. 9 (2021) 136–141. https://doi.org/10.22214/ijraset.2021.32731.

[58] AFGC, - Maîtrise de la durabilité vis-à-vis de la corrosion des armatures et de l’alcali-réaction - Etat de l’art et guide pour la mise en œuvre d’une approche performantielle et prédictive sur la base d’indicateurs de durabilité., 2004.

[59] T. Soleimani, M. Hayek, G. Junqua, M. Salgues, J.-C. Souche, Environmental, economic and experimental assessment of the valorization of dredged sediment through sand substitution in concrete, Sci. Total Environ. 858 (2023) 159980. https://doi.org/10.1016/J.SCITOTENV.2022.159980.