



Dredged marine sand as construction material

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Abstract:

Dredging works are usually required to maintenance activities in many ports all over the world and represents a huge volume of disposal material. The use of dredged aggregates can be considered in several applications as erosive process control, coastal stabilization, beach replenishment, production of construction materials (clay, bricks, aggregates) or construction works (foundation fill, dikes, etc.).

Researches revealed the feasibility of dredged marine sand (DMS) in the construction of base and sub-base harbour pavements incorporating this material to hydraulic binder mixes (cement or lime) in order to improve the grading of aggregates and correct the granular skeleton. Its main objective is to improve the packing and to obtain the compressive properties required for geotechnical applications.

In this work the study of DMS from the Port of Sant Carles de la Rápita (Tarragona, Spain) as construction material is presented. The analysis of its influence on paste, mortar and concrete production is described. Two experimental phases were carried out once chemical and physical characteristics of DMS were determined. At first, pastes and mortars were made using CEM II/A-M 42,5R cement, different percentages of DMS on replacement of raw sand and plasticizer additive in order to obtain fresh and hardened properties of the mixes studied. After that, DMS was used in the production of concretes as fine aggregates. A pilot experience was carried out with concrete port pavements produced in industrial scale. Fresh and hardened properties of the concretes were determined and compared to the control mix. Results show satisfactory behaviour of DMS as construction material when incorporated in concrete as fine corrective sand.

Keywords:

Dredged marine sand – Mortar – Concrete – Mechanical properties

1. Introduction

In the present work a study about the use of dredged marine sand (DMS) as construction material is described. Different samples from Sant Carles de la Rapita Port (Spain) were used for pastes, mortar and concrete production. Chemical, physical and mechanical characteristics were determined. DMS chemical characterisation indicated a negligible contaminant level in all samples studied as described on LIMEIRA *et al.* (in press). According to sieve analysis all samples were characterized as fine material (more than

90% passes through sieve #250 μm) but negligible fine content was found (less than 1% passes through sieve #63 μm). Experimental tests were carried out on pastes and mortars fabricated with different DMS content. The objective was to evaluate its influence in the mixes behaviour with respect to cohesion, workability and strength resistance comparing to control mixes. Concrete was produced in industrial scale in a homologated plant and used in the execution of three experimental sections of a harbour pavement (15 m long, 5 m wide and 25 cm thick, see figure 1). Three different concretes were produced: C1 (control concrete), C2 (concrete made with DMS as fine corrective sand) and C3 (concrete made with DMS as fine corrective sand and reinforced with plastic fibers PF). The fresh and hardened properties obtained were compared with those of control mix.



Figure 1. Pavement execution.

2. Materials and experimental program

2.1 Materials

Mix proportions on pastes and mortars considered initially: type II Portland cement, water, raw sand (NS1 0/2 mm), and different percentages of DMS. A polycarboxilate-based plasticizer (%P by cement weight) was used in some pastes in order to evaluate fluidity and cohesion. Concrete production considered type II Portland cement for maritime environment exposure. Four fractions of limestone raw aggregates: fine aggregates FA1 (0/2 mm) and FA2 (0/5 mm); coarse aggregate CA1 (5/12 mm) and CA2 (12/20 mm) from the plant of Amposta-Masdenverge (UNILAND) were used for concrete production. Physical properties of the aggregates are summarized in table 1.

Table 1. Density and water absorption capacity of aggregates.

<i>Physical properties</i>	<i>DMS</i>	<i>NS1</i>	<i>FA1</i>	<i>FA2</i>	<i>CA1</i>	<i>CA2</i>
<i>Density* (kg/dm³)</i>	2.63	2.65	2.7	2.69	2.7	2.7
<i>Absorption (%)</i>	1	0.4	0.4	0.7	0.8	0.4

**Density on a saturated and surface –dried basis ASTM C-642.*

Polypropylene fiber (FORTA HIERRO®, see table 2) was incorporated in C3 concrete with the objective of enhancing flexural resistance. Polycarboxilate plasticizer (%P) was incorporated in the three concretes in order to achieve acceptable consistence for pumped casting.

Table 2. Plastic fiber characteristics (FORTA HIERRO®).

Fiber characteristics	
<i>Materials</i>	<i>Virgin Copolymer/Polypropylene</i>
<i>Color</i>	<i>Gray</i>
<i>Form</i>	<i>Monofilament/Fibrillated</i>
<i>Fiber System Acid/Alkali Resistance</i>	<i>Excellent</i>
<i>Absorption</i>	<i>Nil</i>
<i>Tensile Strength</i>	<i>620-758 MPa</i>
<i>Compliance</i>	<i>A.S.T.M. C-1116</i>
<i>Length</i>	<i>54 mm</i>
<i>Specific Gravity</i>	<i>0.91 g/cm³</i>

2.2 Experimental program

With the aim of assessing DMS as construction material, fresh and hardened properties of pastes, mortars and concrete were evaluated. Preliminary tests were carried out on pastes and mortars in order to define DMS's role on concrete dosage. The objective was analysing possible DMS behaviour as additive and its influence in fluidity and cohesion of pastes. For this purpose, the use of a plasticizer was considered in some mixes. On the other hand, DMS incorporation on mortars aimed to evaluate its behaviour as fine corrective sand and its influence on compressive strength. The pastes and mortars were produced in a 5-liter Hobart-type blender with two speeds capacities according to ASTM C-305 specifications in laboratory at ambient temperature of 20±2°C. Different percentages of DMS were used on pastes and mortars production considering cement and raw sand replacement. Normal consistence according to EN 196-3, Marsh cone EN 445 and mini slump according to AITCIN (2000) tests were carried out on pastes in order to evaluate consistence, fluidity and cohesion, respectively. On mortars, mechanical behaviour was studied according to EN 196-1.

With respect to concrete production, three different concretes were fabricated in a industrial plant: C1 control concrete made without DMS; C2 concrete made with DMS (on substitution of FA1) and C3 concrete made with DMS (on substitution of FA1) and reinforced with plastic fibers PF. Mechanical tests (compressive strength, elastic modulus, tensile strength with Barcelona-Test and flexural tensile strength) were carried out in order to establish hardened properties of concretes at 28 days of moist curing. Due to the marine environment exposure of structures, volume of permeable pores and capillary absorption tests were also carried out on extracted cores T1, T2 and T3 at 150 days after casting.

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2.2.1 Mix composition

Pastes:

Mix proportions considered initially: cement, water and different substitution or incorporation ratio of DMS by cement weight (see table 2). Mix composition of pastes considered the study of DMS behaviour as additive with the objective of assessing any possible pozzolanic or cementitious activity on its behaviour.

Table 2. Mix proportion of pastes

<i>Materials</i>	<i>Normal consistence</i>			<i>Marsh cone and mini slump</i>		
	<i>PN1</i>	<i>PN2</i>	<i>PN3</i>	<i>P1</i>	<i>P2</i>	<i>P3</i>
<i>Cement (gr)</i>	500	375	250	1200	1200	1200
<i>DMS (gr)</i>	-	125	250	-	300	600
<i>Effective water(gr)</i>	120	100	90	600	600	600
<i>w/c</i>	0.24	0.27	0.36	0.5	0.5	0.5
<i>% P</i>	-	-	-	0-0.5-1	0.5-1	0.5-1-2

Pastes PN1, PN2 and PN3 submitted to normal consistence test were produced using DMS with substitution ratios of 0%, 25% and 50%, respectively, by cement weight. Pastes P1, P2 and P3 were fabricated in order to evaluate fluidity and cohesion by Marsh cone and mini slump tests. Plasticizer content (%P) varying from 0 to 1% by cement weight as well as constant w/c=0.5 were used on the latter mixes. P2 and P3 incorporated 25% and 50% of DMS by cement weight.

Mortars:

Mortar mixes were produced with partial replacement of cement and raw sand by DMS. Dosage 1: 3: 0.5 (cement: sand: water) was adopted in all cases and plasticizer content (%P) was not used in these mortars production (see table 3).

Table 3. Mix proportion of mortars

<i>Material</i>	<i>M1</i>	<i>M2</i>	<i>M3</i>	<i>M4</i>	<i>M5</i>
<i>Cement (gr)</i>	500	375	250	500	500
<i>NS1 0-2 mm sand (gr)</i>	1500	1500	1500	1125	750
<i>DMS (gr)</i>	-	125	250	375	750
<i>Effective water (gr)</i>	250	250	250	250	250
<i>% DMS</i>	0%	25%	50%	25%	50%

Control mortar, M1, was made with 0% of DMS; M2 and M3 mortars were made with 25% and 50% of DMS, respectively, on substitution of cement. M4 and M5 mortar mixes were made with 25% and 50% of DMS on substitution of NS1, respectively.

Concrete:

The mix proportions used in concretes production regarding to marine environment exposure were determined in the industrial plant (see table 4). Aggregate's humidity was corrected and the w/c ratio used considered the total amount of water present on the mixes.

Table 4. Concrete dosage.

Dosage	C1	C2	C3
<i>Cement II /A-M 42.5 R (kg)</i>	335	345	345
<i>FA2: Fine aggregate (kg)</i>	800	700	700
<i>FA1: Fine aggregate (kg)</i>	100	-	-
<i>DMS: dredged sand (kg)</i>	-	150	150
<i>CA1: Coarse aggregate 5/12 (kg)</i>	310	320	320
<i>CA2: Coarse aggregate 12/20 (kg)</i>	640	670	670
<i>Plastic fibers (kg/m³)</i>	-	-	4
<i>Water (litres)</i>	165	165	165
<i>Plasticizer (% by cement weight)</i>	0.74	0.73	0.94

C1 corresponds to control concrete without DMS. Concretes C2 and C3 presented the same dosage with DMS incorporation of 150 kg/m³ (replacing FA1 and partially FA2) except for the incorporation of plastic fibers on C3. A quantity of 4 kg/m³ of polypropylene fibers with 54 mm length according to ASTM.C-1116 was incorporated in C3 concrete. The objective was enhancing the pavement flexural resistance and assessing DMS behaviour in the presence of plastic fibers. Coarse aggregates CA1 and CA2 were increased in 10 kg/m³ and 30 kg/m³, respectively, in order to maintain compressive strength with respect to control mix. In order to achieve acceptable consistence for pumped casting, a polycarboxilate plasticizer was incorporated in the three concretes (0.74%, 0.73% and 0.94%, respectively, by cement weight).

2.2.2 Tests performed

Pastes:

Normal consistence (EN 196-3), Marsh cone (EN 445) and mini slump (AÏTCIN, 2000) tests were carried out on pastes with the objective of assessing fresh properties. Marsh cone test has been used by many researchers in the study of fluidity and determination of appropriate content of super plasticizers in the mixes. The test consists on preparing 1 litre of paste and measuring the time that ½ litre of the paste takes to flow through the needle. Mini slump test procedure is described on AÏTCIN (2000) and consists on filling the mini slump with paste and recording the extension time in seconds from 10 min, 30 min, 40 min and 60 min of the mix fabrication. Final spread of 180±10 mm and

corresponding spread time to reach 115 mm (T_{115}) around 3 ± 1 seconds indicates acceptable cohesion for mixes with optimum filler/cement ratio.

Mortars:

Hardened properties were determined on mortars by compressive and flexural strength tests (EN 196-1). At the age of 7 and 28 days prismatic samples with 40x40x160mm subjected to standard vibration and moist curing were tested.

Concrete:

Tests were carried out on concrete C1, C2 and C3 at 28 days: compressive strength according to UNE-EN 12390, elastic modulus UNE 83316, flexural tensile strength UNE-EN 14651, Barcelona test PrUNE 83-515, absorption and capillary suction UNE 83982. Barcelona test is an indirect tensile test based on the Double- Punching Test (DPT) formerly presented by CHEN (1970). Flexural tensile strength test analyses the tensile behaviour of fiber concrete in terms of residual flexural tensile strength values.

Cores T1, T2 and T3 were extracted from the pavement at 150 days in order to evaluate durability properties on time (volume of permeable pores and absorption ASTM C-642, capillary absorption coefficient UNE 83982, depth of water penetration under pressure UNE-EN 12390).

2.2.3 Results on pastes

Normal consistence:

In order to obtain the normal consistence on pastes PN1, PN2 and PN3 (with replacement of 0%, 25% and 50% of cement by DMS), water-cement ratio increased from 0.24 to 0.27 in PN2 and to 0.36 in PN3. Results indicate slight water demand increase in PN2 comparing to control mix PN1. PN3 presented the highest water demand comparing to the mixes tested.

Marsh cone on pastes:

Pastes P2 and P3 with constant w/c=0.5 considered the incorporation of 25% and 50%, respectively, of DMS by cement weight with the aim of verifying the effect of DMS on the fluidity of the mixes in comparison to control mix P1. It can be observed (table 5) that once DMS content raises the mix fluidity diminishes. However, for 25% of DMS incorporation P2 flow time presented negligible variation comparing to control mix P1. Different behaviour was observed on mixes P3 with 50% of DMS incorporation where flow times presented considerable increase.

Test results indicates, for constants w/c and plasticizer content %P, higher flow time values when 50% of DMS is incorporated to the mixes comparing to those with 0% and 25%. This highlights the influence on DMS on the fluidity loss of the mixes once its incorporation ratio is increased.

Table 5. Flow time on pastes.

<i>Flow time on pastes</i>			
<i>%P</i>	<i>T (sec)</i>		
0,0	20	28	45
0,5	12	19	39
1,0	10	14	21
2,0	-	-	15
<i>% DMS</i>	<i>0% (P1)</i>	<i>25% (P2)</i>	<i>50% (P3)</i>

Mini slump on pastes

In order to evaluate cohesion on pastes, mini slump tests were carried out on mixes (w/c=0.5) with 0% (P1), 25% (P2) and 50% (P3) of DMS incorporation by cement weight. P1 revealed decreasing spread diameter once plasticizer content (%P) rises. On the other hand, the presence of DMS on P2 revealed increasing spread diameter in comparison to control mix when plasticizer content rises (table 6). Slight diameter variation was observed on P3 thus indicating additive effectiveness loss due to the high amount of DMS considered. Studies (GOMES, 2002) revealed that final spread diameter of mini slump usually presents higher values once additives contents are raised and small fillers contents are incorporated to the mixes. Although DMS used in this study presents mineral characteristics rather similar to sands than to fillers, the incorporation of 25% of DMS improved the mixes cohesion with no segregation observed. However, none of the mixes achieved target values according to AITCIN (2000).

Table 6. Mini slump test results on pastes.

<i>Mini Slump – Spread diameter on pastes</i>										
<i>d (cm)</i>	<i>P1 : 0% DMS</i>			<i>P2 : 25% DMS</i>			<i>P3 : 50% DMS</i>			
<i>d₁₀</i>	10.1	8.5	7.65	9	10	12.5	8.4	8.6	10	11
<i>d₂₀</i>	12.5	7.8	7.35	8.6	9.8	13.5	8.2	8.8	9.4	9.5
<i>d₃₀</i>	12.95	8	7.5	8.8	9.2	13.5	8.1	8.5	9.1	8.8
<i>d₄₀</i>	13.15	8.6	6.3	8.5	9.5	13.5	8	8.4	8.7	8.8
<i>% P</i>	0	0.5	1	0	0.5	1	0	0.5	1	2

2.2.4 Results on mortars

Compressive strength on mortars

Compressive strength revealed that M4 presented better results with 3% higher compressive strength than M1 (table 7) at 28 days. Due to fine grading distribution of DMS, its adequate use as corrective sand with NS1 substitution ratio around 25% was checked.

Table 7. Compressive strength of the mortars.

Age (days)	Compressive strength (MPa)				
	M1	M2	M3	M4	M5
7 days	41.2	19.29	8.71	33.63	22.07
28 days	50.05	23.76	12.53	51.57	36.81

2.2.5 Test results in concrete

C1, C2 and C3 concretes satisfied the minimum of 30 MPa compressive strength at 28 days defined for this project (see Table 8). Each presented value is the average of three measurements. With reference to modulus of elasticity, C1 and C2 obtained similar values. C3 obtained the lowest value probably due to extra content of plasticizer added in concrete production and the presence of plastic fibers.

Table 8. Mechanical properties of concretes.

Concrete	Compressive strength (MPa)	Elastic modulus (MPa)	Flexural-tensile strength (MPa)	Tensile strength (MPa)
C1	39 (5%)	28,500 (2,2%)	4.02 (10%)	2.56 (7%)
C2	36(4%)	26,500 (1,2%)	3.67 (10%)	2.53 (3%)
C3	33(5%)	24,500 (0,2%)	3.47 (10%)	2.41 (12%)

The tensile strength determined by the Barcelona-Test (PrUNE 83-515) presented results around 2.5 MPa. Negligible variation was observed on the results revealing slight influence of DMS on the tensile strength of the concretes studied. All concrete mixes satisfied the minimum of 3 MPa flexural tensile strength at 28 days. C1 presented 4 MPa followed by C2 and C3 concretes with respective values of 3.7 MPa and 3.5 MPa. Experimental studies reveal (BENCARDINO *et al.*, 2008) similar results of residual flexural tensile strength for fiber reinforced concretes fabricated with equivalent mix proportion and using ordinary aggregates.

Durability tests carried out in this study are summarized in table 9 for concretes C1, C2 and C3 at the age of 28 days and for cores T1, T2 and T3 at the age of 150 days.

Concrete C1 obtained the lowest volume of permeable pores and lowest capillary absorption coefficient followed by C2 (concrete using DMS on substitution of FA1) and C3 (concrete using DMS and plastic fiber PF). This effect can be attributed to higher effective w/c ratio of C2 and C3 concretes once water absorption capacity of DMS was lower than FA1. Tests results for permeable pore volume on cores T1, T2 and T3 presented slight deviation among different cores measurement of same type of concretes. The water penetration depth (under pressure) value of T1, T2 and T3 pavements cores were lower than the maximum value (5 cm) required by Spanish standard of structural concrete (EHE, 2008) for mass concrete exposed to air marine

environment. Corresponding absorption coefficients of T1, T2 and T3 are summarized in table 9.

Table 9. Durability tests results on concretes.

<i>Concrete</i>	<i>Volume of permeable pores (%)</i>	<i>Capillary absorption coefficient (cm/h^{1/2})</i>	<i>Absorption (%)</i>	<i>Water penetration (cm)</i>	
<i>C1</i>	<i>8.97</i>	<i>0.0441</i>	<i>-</i>	<i>-</i>	
<i>C2</i>	<i>10.05</i>	<i>0.0558</i>	<i>-</i>	<i>-</i>	
<i>C3</i>	<i>11.57</i>	<i>0.0632</i>	<i>-</i>	<i>-</i>	
<i>T1</i>	<i>13.4 (4%)</i>	<i>0.0274</i>	<i>5.9 (5%)</i>	<i>2.03</i>	<i>1.14</i>
<i>T2</i>	<i>12.7 (1%)</i>	<i>0.023</i>	<i>5.5 (3%)</i>	<i>0.90</i>	<i>1.60</i>
<i>T3</i>	<i>12.9 (4%)</i>	<i>0.0236</i>	<i>5.6 (4%)</i>	<i>-</i>	<i>0.92</i>

3. Conclusions

- Paste made with 25% of DMS addition showed adequate fluidity. However, target values for cohesion according to AÏTCIN (2000) were not achieved. The addition of 50% produced huge loss of fluidity and no cohesion improvement;
- Mortar made with 25% of DMS on substitution of raw sand (NS1) presented similar compressive strength to control mortar at 7 and 28 days;
- Tests results on pastes and mortars revealed DMS feasibility as corrective sand rather than addition;
- Mechanical properties (compressive strength, elastic modulus, tensile strength with Barcelona-Test and flexural tensile strength) of concretes made with DMS on substitution of fine sand (0-2 mm) were similar to those of control concrete;
- Concrete C3 obtained lower mechanical properties than control concrete at 28 days of curing. This effect can be attributed to its higher plasticizer content and the presence of polypropylene fibers;
- Control concrete obtained the lowest volume of permeable pores and absorptivity while C3 obtained the highest values probably due to: higher effective water (higher plasticizer content) and the presence of PF which increases its porosity matrix;
- Concrete harbour pavements produced with DMS obtained adequate properties according to water penetration depth under pressure;
- The experimental results obtained in this work show that fine sandy dredged sediment studied can be successfully used as a fine aggregate for concrete production. It is an acceptable material for construction of a harbor road pavement with concrete of 30 MPa;
- Further research is being developed with three different DMS from Barcelona's Port in order to validate its positive behaviour as fine aggregate for harbor concrete pavement. The objective is to assess the effect of higher content of DMS on the mixes.

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