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# Feasibility Study on Utilization of Marine Sand in making Concrete

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***Abstract*— This paper describes the reinforced concrete development using dredged marine sand as an aggregate. The use of sea sand to manufacture cement concrete is not permitted by standards. Even more people are wondered and concerned about the quality and strength of cement concrete using sea sand. Sea sand is not actually used in the technology of cement concrete materials. A sea-sand containing concrete was used for the trials. After analyzing the effect of water/cement ratio, water consumption per cubic meter, curing time, and type of sand on the response "resistance to chloride ion penetration", the dredged marine sand is used for concrete development. An analysis of chloride ion diffusion coefficients at different factor levels was performed. A predictive model of chloride ion diffusion in concrete is developed through regression analysis. The experimental results show that when the water/cement ratio varies from 0.42 to 0.54, and the water consumption per cubic meter varies from 180 to 200 kg, and the curing time varies from 28 to 124 days then the size of the effects fall in the order (most significant first): curing time, type of sand, water consumption per cubic meter, and water/cement ratio. Chloride ion penetration is reduced, and better durability of the concrete is observed, with longer curing times, less water consumption per cubic meter, and a smaller water/cement ratio.**

## INTRODUCTION

Concrete can be considered as the most cost-effective, versatile building material, and when used with steel reinforcement, virtually all structural elements, even complex shapes can be formed. As conventional concrete is placed in its fluid state, there are often significant costs associated with the necessary shutters and formwork to hold the concrete in position whilst it sets and hardens. Aggregates, i.e. sand and gravel, are among the most basic materials fulfilling human needs. They are used for constructions of almost all types of housing. They are used This work was supported in part by the U.S. Department of Commerce under Grant BS123456 (sponsor and financial support acknowledgment goes here). Paper titles should be written in uppercase and lowercase letters, not all uppercase. Avoid writing long formulas with subscripts in the title; short formulas that identify the elements are fine (e.g., "Nd–Fe–B"). Do not write "(Invited)" in the title. Full names of authors are preferred in the author field, but are not required. Put a space between authors' initials.

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for infrastructures fundamental to human well being, such as building roads, dams, bridges, dikes, etc. It is one of the first domestic resources to be utilized in developing economies. Industrialized economies continue to consume large quantities. Of the total requirement more than 90% are extracted from riverbeds and banks [2]. Nowadays, these sources of natural aggregates are in the process of depletion and their extraction also has harmful consequences for the environment. For these reasons, it is important to optimize the consumption of natural aggregates as well as to enhance their replacement by other alternative sources. This research will examine the potential use of fine marine aggregates resulting from maintenance dredging activities as substitutes for natural aggregates for the manufacture of concretes for maritime structures. Marine aggregates offer an easier transport and the possibility of combining the desired size fractions, which can be a considerable advantage in front of land-based aggregates. In this sense, maritime structures such as pavements represent a good alternative for technical, economic and environmental solutions using this kind of material. However, special attention must be paid since a harsh environment and a durability requirement for long live service are indispensable [1] for these structures.

The main applications of dredged marine sand (DMS), apart from beach replenishment, are coastal defenses and land reclamations; however, many countries have opted for the use of marine aggregates in specific civil constructions. Experimental studies about DMS extracted from European and American coasts have shown that these materials are suitable as construction material for the base and sub-base of pavements [3–10]. Also, material from marine deposits around the coasts of Great Britain has been used in concrete production for several decades [11]. Other notable examples are: the construction of Rotterdam Harbor (Netherlands), the Great Belt Bridge (between Denmark and Sweden), the Thames Barrier, London's National Theater, or the Tamar Bridge of Plymouth (UK). Outside Europe there are also remarkable constructions like the artificial island of Chek Lap Kok, where the Hong Kong Airport is located. The Palm Islands and other artificial islands in Dubai [12] is shown in Fig. 1. The usages of marine aggregates (MA) in different countries in last two years are listed in Table 1.

The chloride ions present in sea sand, however, make its application potentially threatening to the durability of concrete structures made using it [13-16]. The NEL test of chloride ion diffusion was used to conduct an experimental study on the durability of sea-sand containing concrete materials [17]. An orthogonal experiment with the factors water/cement ratio, water consumption per cubic meter, curing time, and the type of sand was performed. The effect of

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these factors on the prevention of chloride ion permeation is analyzed and a predictive model is presented that allows further optimization of the durability of sea-sand containing concrete. Research to use sea sand for construction, especially, using sea sand to make the cement concrete is aimed to exploit maximally the potential of a local material being available, cheap for socioeconomic developing and prevent from its harmful impaction. However the study to use sea sand cement concrete is a big problem of civil engineering field. In many countries sea sand have been using for making cement concrete since long time ago, naturally, its technology depends on the research achievement and specific conditions of each country.

Table 1. Usage of marine aggregates in different countries (Data obtained from Ices)

| Country | MA extracted (million $m^3$) | Construction Industry (%) | Beach Replenishment (%) | Exports (%) |
|---|---|---|---|---|
| Belgium | 1.63 | 93.8 | 6.2 | 0 |
| Denmark | 7.1 | 59.9 | 38.8 | 1.4 |
| Netherlands | 29.07 | 49.2 | 43.4 | 7.4 |
| Poland | 0.64 | 2.9 | 79.6 | 17.5 |
| Spain | 0.48 | 0 | 100 | 0 |
| UK | 13.13 | 66.6 | 4.8 | 28.8 |

## 2. LITERATURE REVIEW

According to Gutt and Collins [18], the geological origin of marine aggregates is similar to that of the aggregates commonly used in the manufacture of concrete. In fact, natural or raw aggregates were submerged due to rising sea levels since the ice age. The main differences detected between the raw aggregates and those from marine dredging are the presence of salts, shells and possible content of organic matter in the latter ones. These aspects must be controlled if they are used as constituents of concrete, because in excessive amounts they can trigger the development of different pathologies such as corrosion of the reinforcement or increase of permeability. The evaluation must be carried out taking into account the properties of the aggregates with respect to the requirements for the particular use to which they will be subjected in the concrete. Size fraction is usually the main property used for DMS characterization. A high proportion of dredged sand usually presents a fraction of material that passes through the 125 lm sieve. However, fine particle content changes with location and time. With respect to the salt content, aggregates from marine dredging have the same chlorides and sulfates than seawater. Moreover, due to the proximity to harbor areas where dredging tasks are performed, it is necessary to consider an additional kind of pollution such as heavy metals. In the United States, studies [19] carried out on dredged aggregates from different harbors have concluded that there were low concentrations of heavy metals in them (lead, chromium, mercury, arsenic, cadmium), as well as PCB's and cyanide. It is important to note that the fine size fraction of marine aggregates and the presence of contaminants play an important role, since the dimension of the sediments is directly related to the latter composites: the smaller the grains (<63 lm), the higher the presence of contaminants.

Several European countries have their respective standard policies of marine aggregates with respect to contamination and disposal. The EC itself has no specific limits for contaminant levels in dredged material, but a summary of various countries' action levels for heavy metals can be found in the literature [20]. If concentrations of these substances exceed the limits, a treatment is required. Some decontamination techniques like the stabilization of heavy metals and organic thermal elimination are often used [21]. Other treatments that have been successfully developed are the chemical treatment, the heat treatment and the pulverization treatment. A Columbia University Treatment (CUT) is described in a US patent application [22] seeking to reduce the contaminants of the dredged material. This procedure was adopted in a research [23] about the beneficiation of dredged material from the Port of New York and New Jersey. According to the author, destruction of the conglomerates in dredged material is necessary prior to or during detoxification, as in the case of heavy metals or other inorganic toxic elements. In general, the main goals of the detoxification process are the immobilization and the encapsulation of heavy metals. The results obtained revealed that the prior CUT treatment of dredged material used as filler in mortar production led to better results in comparison with untreated dredged material. In the Netherlands, a research [24] with a fine size fraction of dredged material sintered to produce artificial gravel or bricks revealed that contaminated materials could be permanently sealed into the end-product. In Germany, a pilot experiment [25] was conducted at full-scale with industrial brickworks. Bricks were produced according to German industrial standards using clayey, slightly sandy silt from the harbor basin of Bremen. Treated dredged material improved the plastic properties and decreased segregation, and the effectiveness of cement in binding metals and in preventing leaching was observed with neither lead nor cadmium being detected in samples submitted or not to any treatment.

Considering the use of uncontaminated and in consequence untreated DMS as a component of cementitious materials, a study conducted at the UPC by Limeira et al. [26] evaluated the influence of its incorporation on the behavior of pastes and mortars. It was noted that to obtain the same consistency, cementitious materials made with DMS in partial substitution of raw sand required more water than those made with raw sand. Besides, an increase in the amount of DMS in the mixture decreased its fluidity. Furthermore, mortars made with 25% of DMS provided strength similar to that of the reference mortar (without DMS). Limeira et al. [27] also researched the mechanical and durability properties of concretes fabricated at industrial scale with 18% of DMS in replacement of raw sand. Port pavements with a width of 5 m, a length of 25 m and a thickness of 25 cm were built. The concretes fulfilled the required plant design characteristics with respect to batching and transportation by settling truck, placing and finish with adequate workability. The concretes made with DMS incorporation showed similar results for fresh and hardened tests with respect to the control mixture. The experience revealed the successful use of DMS as fine aggregate for concrete of 30 MPa. The study conducted by Columbia University [23] on mortars and concretes manufactured by replacing raw sand with dredged marine material of a very fine fraction (10 lm) revealed that the strength reached by those made with part of dredged material was lower than that of the control mixture, and the mixtures were less workable. However, the increase in strength over time was higher than in those containing only raw aggregates. Finally, the study carried out by Agostini et al. [21] on mortars made with polluted dredged sediments from the Dunkirk Harbor (France) submitted to treatment revealed that the processed material (TSA) presented high porosity (60%) and absorption (45%) and high fine content. Mortars made with partial substitutions of raw sand (33%, 66% and 100%) by dredged material produced a significant increase in strength for low to moderate substitution ratios, while a high incorporated quantity led to strength of the same order as the control mixture. There was also a sharp increase in shrinkage, yet the permeability remained constant.

Despite the several research studies about the use of dredged sediments as construction material recently published [28–32], little information and reliable technical data are available regarding the properties of concretes made with marine aggregates and their suitability as such a material. This work aims at encouraging the discussion of the beneficial use of this material in concrete production. In this research, three DMS samples were extracted from the Port of Barcelona and were used in partial replacement of raw sand in the manufacture of concretes designed for harbor pavements. The material was stockpiled in the open air and no washing, drying or decontamination process was carried out. The mineralogy of the samples was determined by X-ray diffraction. The chemical characterization identified the contents of water-soluble chlorides, sulfates, organic matter and heavy metals. Physical tests were carried out in order to determine particle size, density and absorption.

## 3. MATERIALS AND METHODS

### 3.1. Tests on aggregates

The offshore sand samples were obtained from Pondicherry, India. A large sample was obtained of sand that appeared to be typical of the dredged material. In addition, smaller samples were obtained of sand that appeared to be of coarse, fine and medium grading. The fine sand was obtained from the top surface of material that had been just dredged and settled; as such it may not be a truly representative sample, but constitutes an extreme case. The coarse aggregate, with which the sea sand was used to produce concrete, was a well graded crushed gneissic material of 20 mm maximum aggregate size. The fine aggregate grading tests were

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carried out as per [33]. The shell content was measured for coarse, medium, fine and typical grading of offshore sand, from a sample size of 1000 g .

3.2. Materials

A 42.5R grade Portland normal consistency, mortar strength cement with a density of 3.18 g/cm3, a specific surface area of 325m2/kg, a fineness of 0.75%, and containing 29.8%water was used. Coarse aggregate gravel with a grain size of 5-31.5 mm, a pin sheet content of 6.7%, and a clay content of 0.63% was used as aggregate. The fine aggregate consisted of three sands. One was sea-sand consisting of fine sand (Mx = 2.25) with a clay content of 1.93%; this is desalted sea-sand. A second sand was a medium sand (Mx = 2.46) with a clay content of 0.48% that was a river-sand. The third sand was a medium sand (Mx = 2.77) with a clay content of 2.84%. The grading, density and absorption of DMS were obtained as the average of three values. The three specimens were obtained by sampling the huge sample according to UNE-EN 932-1 [34]. The orthogonal experiment lays emphasis on the effect of the water/cement ratio, the type of sand, the curing time, and the water consumption per cubic meter. The response variable was the durability of the sea-sand concrete. Three levels were used for each factor and they are tabulated in Table 2.

| Factor level | Sand type | Water/Cement ratio | Curing time (days) | Water consumption per cubic (Kg) |
|---|---|---|---|---|
| 1 | Sea sand | 0.42 | 28 | 180 |
| 2 | Sea sand and River sand | 0.48 | 72 | 190 |
| 3 | Diluted sea sand | 0.54 | 124 | 200 |

3.3. Experimental program

An experimental program was carried out using different DMS samples from the Port of Barcelona for concrete production. The study aimed at determining the enhancement of the mechanical and durability properties of concretes based on the optimum raw sand substitution ratio by DMS. Eight different mixtures incorporated DMS-A, DMS-B and DMS-C as granular corrector in partial substitution of crushed limestone raw sand, FA1. The percentage ranged from 15% to up to 50% by aggregate mass. Table 3 summarizes the nomenclature of the mixtures used.

| Concrete | Nomenclature |
|---|---|
| Reinforced concrete | RC |
| Concrete with 15% DMS-A | CA 15% |
| Concrete with 25% DMS-B | CB 25% |
| Concrete with 35% DMS-B | CB 35% |
| Concrete with 25% DMS-C | CC 25% |
| Concrete with 35% DMS-C | CC 35% |

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### 3.3.1. Concrete mixture composition

The dosage proportion adopted in the study of concretes made with DMS from the Port of Barcelona was suggested by an industrial plant specializing in the construction of port pavements. It was designed following the recommendations from the ‘‘Design and construction of port pavements’’ (ROM 4.1 – 94) [36] and chapter 2 of the EHE [35] regarding the required exposure to the marine environment (a minimum amount of cement of 300 kg/m3 and the maximum total w/c ratio of 0.5). The dosage used for all concretes considered 329 kg of cement/m3 and an effective w/c ratio of 0.44 (the amount of water which reacted with the cement). As mentioned above, none of the concretes reached the total w/c ratio of 0.5. The total water (free water) added to the mixing machine was calculated by the sum of the amount of water reacting with the cement and that absorbed by the aggregates at the time of concrete production. The aggregates were used dry and the content of water present in the plasticizer additive was corrected. The reference concrete (RC) was fabricated using three aggregate fractions: FA10/4 mm, CA1 4/12 mm and CA2 12/20 mm. One type of concrete named CA15% was fabricated with 15% of DMS-A in substitution of FA1 0/4 mm. Three different concretes were produced with DMS-B using 25%, 35% and 50% of DMS-B in substitution of FA1 0/4 mm. These concretes were named CB25%, CB35% and CB50%. The same types were produced with DMS-C and were named CC25%, CC35% and CC50%. The use of a plasticizer additive was adopted in order to achieve homogeneous mixtures with the required consistency of concrete considering the highest amount of DMS incorporation.

### 3.3.2. Fresh and hardened concrete properties

The tests performed and the corresponding standards are detailed in Table 9. Slump test, compressive and flexural tensile strength tests were carried out in all concretes fabricated. Concretes made with DMS-A were then discarded because their workability and compaction could not achieve an acceptable performance. Further tests were thus carried out on concretes fabricated with DMS-B and DMS-C using 35% and 50% of FA1 0/4 mm substitution: splitting tensile strength, elasticity modulus, abrasion, impact strength, ultrasound, density, absorption and accessible pores, sorptivity and water penetration under pressure. All tests were carried out according to EN specifications. The specimens were cast in cylindrical and prismatic steel molds and compacted by vibrating table. After casting, the specimens were covered with a plastic sheet for 24 h, and then were unmolded. After that, the specimens were cured in a humidity chamber at $21^0$C and 95% of humidity until the test age was reached. The volume of permeable pores and absorption, sorptivity as well as the water penetration depth under pressure was determined at the age of 28 days of moist curing. Cylindrical specimens with a diameter of 15 cm and a height of 15 cm were used for the last test. Tests of sorptivity and volume of permeable pores were carried out on cubic specimens of 10 cm. For sorptivity determination, the bottom face of the molded specimens was in contact with the water flow. The cumulative water absorbed was recorded at different time intervals of up to 2 h by weighing the specimen after removing the surface water using a dampened tissue. Then the amount of water absorbed was calculated and normalized with respect to the cross-section area of the specimens. Sorptivity is the slope of the regression curve of the quantity of water absorbed by a unit surface

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area versus the square root of the elapsed time from 10 min to 120 min. The solubility of different samples in water are provided in Table 4.

| Samples | Chloride (Cl) % | Sulfate ($SO_3$) % |
|---|---|---|
| DMS-A | 1.70 | 0.23 |
| DMS-B | 0.13 | 0.16 |
| DMS-C | 0.10 | 0.46 |

**RESULTS AND DISCUSSION**

The deterioration of concrete structures is usually caused by the penetration of external aggressive agents. Therefore, the durability of concrete is strongly related to the quality of the first few centimeters of material below the surface (coverage) [37]. The volume of accessible pores, as well as water penetration under pressure and sorptivity are considered as durability indices because they are useful to quantify the resistance of the materials against the penetration of external agents. For this reason they have been subjected to several studies [38, 39], and in all cases direct relationships have been found among these properties, which means that if the porosity increases, so do the water penetration under pressure and the sorptivity.

Due to different environmental conditions, production and curing process, different properties of concrete test specimens and pavement cores were observed. However, considering the individual analysis of each of the three concrete groups at the ages of 25 and 125 days, a consistent comparison can be made among them. The volume of permeable pores in cores is higher than in test specimens, probably due to the evaporation of free water and the lack of curing time in pavement maintaining process. According to Neville [37], absorptivity values obtained in the first 4 h can be correlated with concrete w/c ratios. The values of 0.09 mm/min1/2 and 0.17 mm/min1/2 correspond to concretes with w/c of 0.4 and 0.6, respectively. In this study (Fig. 2) absorptivity on cores T1, T2 and T3 achieved values around 0.08 mm/min1/2, while specimens C1, C2 and C3 presented values around 0.12 mm/min1/2. It must be noted that the external face of the cores was composed of coarse aggregates and mortar, which were in contact with the water flow. However the test specimens had an external molded face (mortar) in contact with water. The water flow was submitted only by gravity; no pressure was used in the test procedure. It can be concluded that the pore structures of the concretes presented considerable differences, probably related to the variability of environment and cure condition (laboratory and work field), and consequently the test specimens obtained a lower permeable pore volume. The capillary absorption capacity on cores presented a reduced effective area for flow due to the presence of aggregate in the external face, when compared to the test specimens. This could justify the considerable difference observed between the test results found at 25 and 140 days with regard to compressive strength, permeable pore volume and water suction (capillary absorption coefficient).

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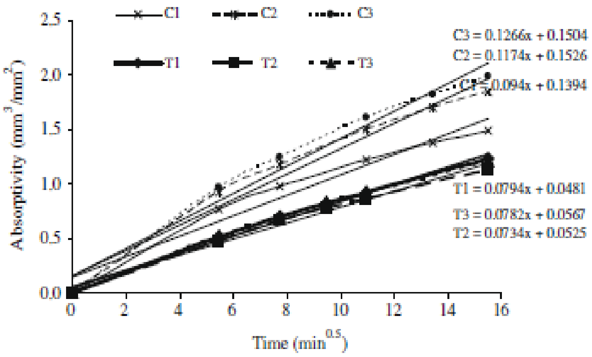
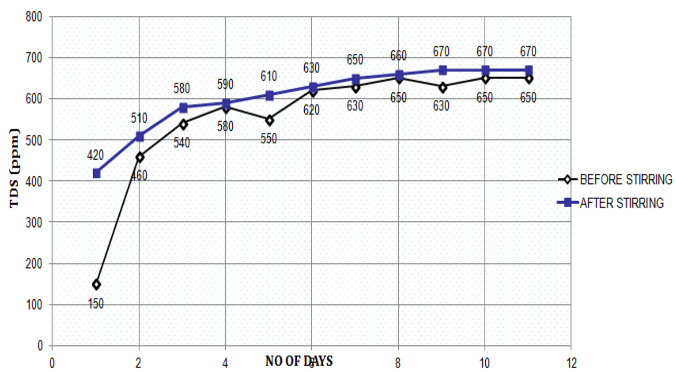



The CC concretes showed the best parameters as regards durability properties, with results highlighting lower water penetration depth, sorptivity and accessible pores. However, such parameters were augmented by increasing DMS incorporation. With respect to the UPV test, several studies have been developed with the aim of finding a direct relationship with the compressive strength of concrete [40,41]. The results obtained for the solubility test is provided in table 3 and the comparison is made between before stirring and after stirring in Fig. 3.

| Description | Quantity |
|---|---|
| Weight of sample taken | 300g |
| Volume of Water | 250 ml |
| TDS in tape water | 50 ppm |
| TDS after 16 days | 670 ppm |
| Increase in dissolved salt concentration | 620 mg/l |
| Amount of salts removed from sand | 155 mg |
| % of salts removed from sand | 0.052% |



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The simulated rain test result is given in table 4 and it shows some improvement in salt removing process comparing to solubility test.

| Description | Quantity |
|---|---|
| Height of the vertical pipe | 155 mm |
| Rate of flow | 138 ml/hour |
| Weight of sample taken | 50 g |
| Diameter of pipe | 19 mm |
| Total dissolved salt in Normal water | 50 ppm |
| Total volume of water | 1104 ml |
| Final value of TDS | 60 mg |
| Total concentration of dissolved salts | 66.24 mg |
| % of salts removed from sand | 0.13 % |

## V. CONCLUSION

The effects of standard curing time, water consumption per cubic meter, and water/cement ratio on the chloride ion diffusion coefficient of a sea-sand concrete are very significant. The chloride ion diffusion coefficient increases as the water cement ratio increases also it decreases as the water consumption per cubic meter decreases. It declines with an increase in standard curing time. A chloride ion diffusion dead set against and more durable concrete is obtained with a smaller water cement ratio. The concrete hydration is a long and slow process. The adoption of twenty five days as the standard curing time when evaluating the concrete permeability does not allow enough time to obtain an accurate assessment of the permeability of fully cured concrete. When the water cement ratio falls within a range from 0.42 to 0.54 water consumption per cubic meter has more effect on the chloride ion diffusion coefficient than water cement ratio. The proposed method provides a reference for designing durable structures using sea-sand concrete in coastal areas.

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