Studies on Long Term Performance of Concrete using Dredged Marine Sand

By

Patel Satvik J.

11MCLC10

DEPARTMENT OF CIVIL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

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Major Project

Submitted in Partial Fulfillment of the Requirements for Semester-IV of

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CIVIL ENGINEERING

(Computer aided structural analysis and design)

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) at Nirma Univeraity and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Patel Satvik J.

Certificate

This is to certify that the Major Project entitled **"Studies on Long-Term Performance of Concrete using Dredged Marine Sand"** submitted by **Patel Satvik Jatinkumar (Roll No: 11MCLC10)** towards the partial fulfillment of the requirements for the degree of Master of Technology (CIVIL Engineering) in the field of Computer aided structural analysis and design of Nirma University is the record of work carried out by him under our supervision and guidance.The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date:

Dr. Urmil V. Dave
Guide and Professor
Department of Civil Engineering
Institute of Technology
Nirma University
Ahmedabad

Dr. Paresh H. Shah
Professor and head
Department of Civil Engineering
Institute of Technology
Nirma University
Ahmedabad

Dr. K. Kotecha
Director
Institute of Technology
Nirma University
Ahmedabad

Examiner

Date of examination

Abstract

Nowadays concrete is most importantly used material in almost all structures as a basic material. The sand which is taken generally from quarries or alluvial rivers is a basic ingredient for manufacturing the concrete. But this source of sand is in a state of depletion and their further extraction may cause harmful effects on environment. To counteract this problem some other sources have to be found out and studied as well as experimented. Some of the alternates are dredged marine sand, offshore sand, dune sand, quarry dust and washed soil which also have to be used for replacing the fine aggregate. Thus the use of natural river sand in concrete is to be minimized and saving the natural resource of river is to be made

Two concrete grades are used in the concrete i.e. M25 and M40. Two types of cements are used in the concrete i.e. OPC and PPC. Three different concrete mixes are taken in to consideration for the experiment i.e. Mix-A (concrete made using 100% natural river sand), Mix-B (concrete made using 50% replacement of natural river sand with dredged marine sand) and Mix-C (concrete made using 100% replacement of natural river sand with dredged marine sand.

The project mainly concentrates on the use of Dredged marine sand (DMS) as a fine aggregate during casting of concrete and evaluating the mechanical properties like compressive strength & Durability properties. Sulfate, Acid and Chloride exposure , Sorptivity, Water absorption for plain concrete cubes and Accelerated corrosion test for Reinforced concrete cylinders has been attempted in present investigation. Standard size concrete cubes are cast as per IS provisions. Change in the appearance and change in mass after exposures in all chemicals are observed and studied for durability properties. Also the non-destructive testing is performed for the concrete specimens.

The results related to mechanical and durability properties for all concrete mixes

have suggested adequate performance of concrete made with dredged marine sand as compared to the concrete with natural river sand. Mechanical properties of concrete made with dredged marine sand indicate higher results for concrete Mix-C made with 100% dredged marine sand as compared to that of concrete Mix-B made with 50% replacement of river sand with dredged marine sand and concrete Mix-A made using 100% natural river sand at the end of 56 days curing.

Durability properties like acid and sulfate resistance of concrete made with dredged marine sand show better performance for concrete Mix-C made with 100% dredged marine sand as compared to that of concrete Mix-A made using 100% natural river sand and concrete Mix-B made with 50% replacement of river sand with dredged marine sand after completion of 3 months of exposure in acid and sulfate solution, respectively. Chloride resistance test suggests that concrete made with dredged marine sand show less resistance against chloride solution for 2 months of exposure to presence of chloride in dredged marine sand. Sorptivity and water absorption test indicate almost similar results for concrete made with dredged marine sand as compared to that with natural river sand. Concrete Mix-C made with 100% dredged marine sand shows better resistance against the corrosion as compared to concrete Mix-A made using 100% natural river sand and concrete Mix-B made with 50% replacement of river sand with dredged marine sand.

Thus investigation suggests successful use of dredged marine sand in concrete as a fine aggregate in construction activities. Furthermore investigation is to be done related to the chloride resistance of concrete with dredged marine sand.

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Satvik J. Patel
11MCLC10

Nomenclature

DMS .... Dredged Marine Sand

M25 .... Standard Concrete Grade

M40 .... Standard Concrete Grade

OPC .... Ordinary Portland Cement

PPC .... Portland Pozzolana Cement

Mix-A .... Concrete made by using 100% natural river sand

Mix-B ...... Concrete made by 50% replacement of natural river sand with dredged marine sand

Mix-C ..... Concrete made by 100% replacement of natural river sand with dredged marine sand

UPV .... Ultrasonic Pulse Velocity

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Chapter 1

Introduction

1.1 General

In manufacturing the concrete, most of the aggregates which are being used as a fine aggregate are taken from quarries or alluvial rivers. Nowadays, these sources of natural aggregates are in the state of depletion and their extraction also has harmful consequences on the environment. For this reason, one needs to think of some other alternate such as offshore sand, dune sand, quarry dust and washed soil which have also been made use for replacing the fine aggregate by other material and thus to minimize the use of natural river sand in concrete.[3]

One can think of an option of using Dredged marine sand (DMS) as a fine aggregate which can, on the other hand be proved to be useful in maintenance of dredging activities for offshore structures or maritime structures. Marine aggregates offer an easier transport and the possibility of combining the desired size fractions, which can be a considerable advantage as compared to that 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.[1]

Fig 1.1 shows the dredged marine sand which is sieved using 4.75 mm sieve. The dredged marine sand used in manufacturing of the concrete as a replacement of natural river sand was extracted from the South port area of Mundra port in Kuchch district.

Figure 1.1: Dredged marine sand

Dredging works (enlarging and deepening access channels, achieving appropriate water depths along waterside facilities, etc.) are usually required in order to carry out maintenance activities in many ports all over the world. The dredging work mainly includes removing accumulated sediments from the bottom of dredged channels etc. is also necessary.[2]

Initially the primary investigation is done using the raw dredged marine sand and not the processed sand to see the behavior and effects of the sand in the concrete whether concrete works well with the row sand or not. Fig 1.2 shows IHC Beaver Cutter Suction Dredger 6520C and booster which are used for extracting the dredged marine sand.[24]

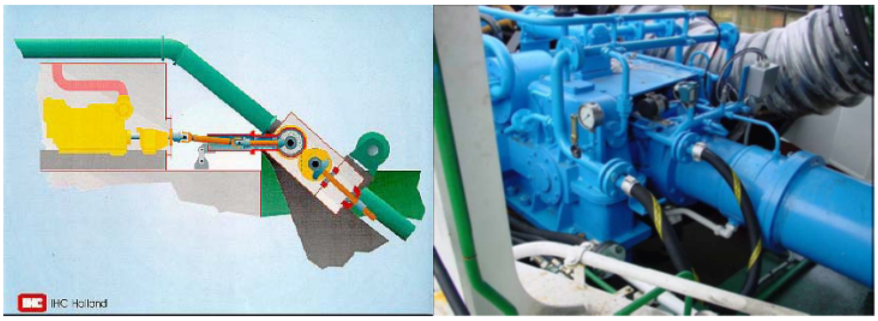

Figure 1.2: IHC Beaver Cutter Suction Dredger 6520C and booster [3]

Fig 1.3 shows the Cutter suction dredger which is right now used at Mundra port for dredging the marine sand and its details are given as follows.

Figure 1.3: Cutter suction dredger

Details of the Cutter suction dredger shown in the Fig 1.3 with respect to its dimensions and dredging capacity are as follows.

- Type: Stationary cutter suction dredger
- Overall length - 104 m
- Width - 18.6 m
- Depth - 5 m

- Dredging Capacity - 29m

The offshore sand extracted generally from below around 15 m of ocean depth would not affect the coastal sediment budget. It has been found that the dredging and pumping costs would be around 90% of the stockpiled sand cost and the transport cost is also not excessive as of natural river sand.[3]

Experimental studies for 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. Also, material from marine deposits around the coasts of Great Britain has been used in concrete production for several decades.[1]

One company namely "Bio-active live aragonite" provides the nature's ocean aquarium sand. Basically the company belongs to U.S.A and supplies various types of marine sand for the Aquarium. Other than that Carib-sea arag alive and Bulk reef supply also provide such sea sand. Fig 1.4 shows such use of natural marine sand for aquarium.

Figure 1.4: Use of marine sand for Aquariums

Other examples are the construction of Rotterdam Harbor (Netherlands), the Great Belt Bridge (between Denmark and Sweden), the Thames Barrier, London's National Theater, 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 in Dubai.[1]

1.2 Research Significance

The importance of this study is to experiment and evaluate the effects of replacement of river sand with dredged marine sand (DMS) which can be proved to be a new material for construction activities. The effects with respect to mechanical and durability properties of concrete are to be studied.

Nowadays concrete is most importantly used material in almost all structures as a basic material. The sand which is taken generally from quarries or alluvial rivers is a basic ingredient for manufacturing the concrete. But this source of sand is in a state of depletion and their further extraction may cause harmful effects on environment. To counteract this problem some other sources have to be found out and studied as well as experimented.

The research is done mainly to determine if dredged marine sand is used as a replacement of river sand in concrete, how the effects on concrete with respect to mechanical and durability properties differ as compared to concrete made with river sand.

If the investigation will allow the successful usage of the dredged marine sand which replaces the river sand in concrete as a fine aggregate, we can minimize or eliminate the use of river sand and thus minimizing the harmful effects on environment by saving the source of river sand.

So far the dredged marine sand was only been used for the construction of the pavements, foundations, piles etc. Furthermore, it could be more realistic and flexible in developing construction activities if this usage of marine sand is utilized and can be used in the construction of super-structures.

1.3 Objectives of study

To study the effects of dredged marine sand in concrete, following objectives are decided for major project work.

- To evaluate modification in compressive strength for two different grades of concrete using two types of cements & comparison between all of them individually for different dosages of dredged marine sand.
- To study the variation in compressive strength for two different grades and cements and comparison of them with each other for different dosages of dredged marine sand.
- To study durability properties such as acid, sulfate & chloride resistance of concrete after various exposure ages and exploring their compressive strengths, change in compressive strength and change in mass respectively for all concrete mixes.
- To evaluate the water absorption and sorptivity of plain concrete specimens and their comparison for all concrete mixes.
- To evaluate rate of corrosion using impressed current technique on RC cylinders for all concrete mixes after performing accelerated corrosion test.
- To evaluate most appropriate dosage of dredged marine sand out of two dosages i.e. 50% and 100% replacement of natural river sand.

1.4 Scope of work

The scope of work for the major project is mainly divided in to two parts which are as follows.

(A) Investigation pertaining to Plain concrete:

The work is mainly focused on the studies of mechanical property i.e. compressive strength and durability properties of the concrete exposed to different exposures. Overall scope is presented in Figure 1.5 & Figure 1.6 respectively. Details of three mixes, both concrete grades and both cement types are given in Table 1.1.

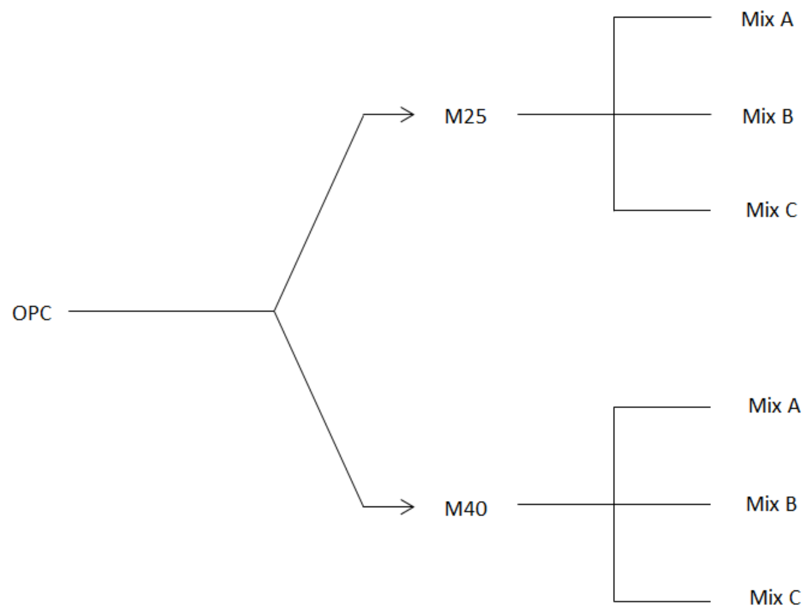

Figure 1.5: Scope for OPC, two grades and three concrete mixes

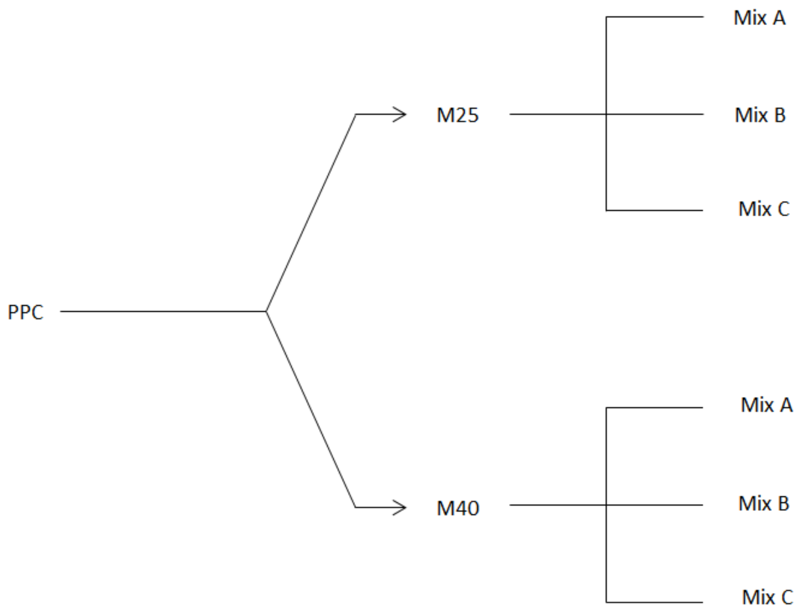

Figure 1.6: Scope for PPC, two grades and three concrete mixes

Table 1.1: Details of concrete mixes

1.	OPC	Ordinary portland cement
2.	PPC	Portland pozzolana cement
3.	M25	Standard concrete grade
4.	M40	Standard concrete grade
5.	Mix-A	Control concrete made with 100% natural river sand
6.	Mix-B	Concrete made with 50% replacement of natural river sand by dredged marine sand
7.	Mix-C	Concrete made with 100% replacement of natural river sand by dredged marine sand

Two concrete grades are taken into considerations which are M25 and M40 for the experimental work. Two different types of cements are taken i.e. OPC and PPC. Two different dosages of dredged marine sand are decided to be taken for the experiment i.e. 50% replacement and 100% replacement which are Mix-B and Mix-C respectively.

Overall 12 mixes are made for evaluating various parameters of concrete using dredged marine sand. It is planned to cast 432 cubes of size 150 mm X 150 mm X 150 mm for the whole work. Average results of three cubes are to be taken for the final result. It is planned to cast total 108 cubes for evaluating the compressive strength of concrete for all mixes after 7, 28 and 56 days of moist curing. For the durability aspects, total 108 cubes are to be cast for water absorption, sorptivity test and chloride resistance test respectively i.e. 36 cubes for each test. Further, for other durability properties 216 cubes are to be casted for acid and sulfate resistance test of concrete i.e. 108 cubes per test.

Acid resistance test: Dosage for the acid exposure to concrete mixes is 5% H_2SO_4 (sulfuric acid) of the total volume of water. Exposure ages are 3 months, 6 months and 12 months after 28 days of moist curing for all cubes. Change in compressive strength and change in mass are to be measured after completion of exposure at each age for concrete mixes.

Sulfate resistance test: Dosage for the sulfate exposure to concrete mixes is 5% Na_2SO_4 (sodium sulfate) of the total weight of water. Exposure ages are 3 months, 6 months and 12 months after 28 days of moist curing for all cubes. Change in compressive strength and change in mass are to be measured after completion of exposure at each age for concrete mixes.

Chloride resistance test: For this test, the content for the chloride exposure to concrete mixes is 3% NaCl (sodium sulfate) of the total weight of water. Exposure age is only 2 months after 28 days of moist curing for all cubes. Change in compressive strength and change in mass are to be measured after completion of exposure at each age for concrete mixes.

It is also planned to observe the variation in appearance of immersed concrete specimens after completion of the designated exposure in all three chemicals.

(B) Investigation pertaining to the cylinders exposed to accelerated corrosion test is mainly focused on following parameters:

This part includes the RC cylindrical specimens of concrete mixes having one HYSD bar and one Stainless steel bar to serve as the anode and the cathode for completing the circuitry respectively.

Three cylinders each for 12 concrete mixes having dimension 300 mm height and 150 mm diameter are to be cast. Accelerated corrosion mechanism using impressed current technique with chloride immersion for inducing corrosion in the cylinders is to be implemented. Proper circuitry is required to be used for inducing electrochemical corrosion for the cylinders.

The cylindrical specimens are required to be water cured for 28 days. They are to be exposed in NaCl solution with DC power supply using Rectifier. On observation basis the corrosion in the reinforcement is to be detected after completion of 1 to 2 weeks. UPV test is to be used as non-destructive test and corrosion rate in the reinforcement is to be measured using half-cell potentiometer before and after the test.

Average result of three cylinders is to be considered as a final result in terms of variation in above parameters.

1.5 Layout of report

The report of the major project is mainly classified into five chapters which are given as below.

Chapter 1 shows the discussion about the general overview and the significance of the project and also having the objectives & scope of work for the experiment.

Chapter 2 describes literature review which is having mostly the research work pertaining to this project done in past. It includes properties of dredged marine sand, percentage replacement and their effects on mechanical and durability properties of concrete and applications of dredged marine sand in concrete as a fine aggregate.

Chapter 3 discusses about the whole experimental work in detail. The chapter is having concrete mix design, properties of marine sand used in the casting work, whole casting work details and the process of all the tests.

Chapter 4 includes all the results and discussions with respect to the mechanical properties as well as durability properties. The mechanical properties include compressive strength for different ages of curing. Durability properties such as acid resistance, sulfate resistance, chloride resistance, sorptivity test and water absorption test are also taken into consideration. The test related with the RC cylinder, which is Accelerated corrosion test is also considered in this chapter.

Chapter 5 is having the concluding remarks, summary of the whole project and the future scope of work for the major project work.

Chapter 2

Literature review

2.1 General

This chapter explains the brief understanding of how the usage of dredged marine sand can be utilized as an alternative material instead of the natural river sand as fine aggregate in manufacturing of concrete. It mainly includes the research work as well as experiments done in past, the allowable dosage, mechanical and durability aspects, mineralogical, physical & chemical properties of dredged marine sand.

2.2 Studies on Mechanical and Durability properties of dredged marine sand

2.2.1 Physical, Chemical and Mineralogical properties of Fine Aggregate

Limeira et al. [2] described the experimental work on three different sections and with three different concretes. The influence of dredged marine sand (DMS) from Port of Sant Carles de la Rpita (Tarragona, Spain) as a fine aggregate on the production of concretes was analyzed, and its properties were determined.

The study presented the physical, chemical and mineralogical properties of the DMS which was extracted from the Port of Sant Carles de la Rpita (Tarragona, Spain) and stockpiled in the open air for 3 months. Then after five representative samples of 1 m3 of DMS from different locations and submitted to sampling in order to determine the above properties. The grading of DMS, determined according to UNE-EN 933-1 specifications.

Grading of the DMS as compared to regular sand and Coarse aggregate is shown in Fig 2.1 below.

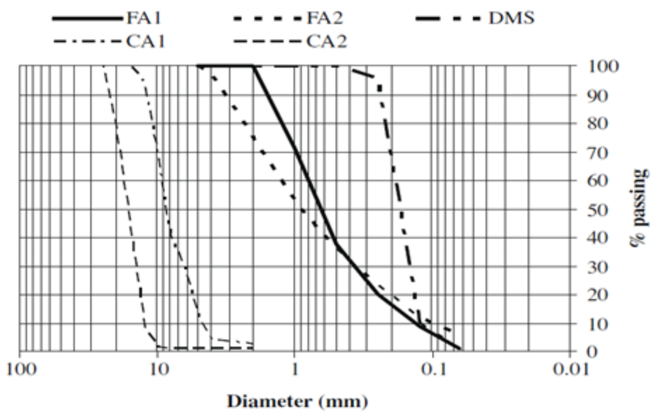

Figure 2.1: Grading curves of fine and coarse aggregates

Fig 2.1 shows the physical characterization showed that the DMS used in this research work presented a considerable content of high fine particles with more than 95% of the material passing through 0.25 mm according to the sieve analysis.

Molina et al. [1]had given the grading of the DMS samples. The samples for testing were obtained by sampling 1 m3 of each DMS extracted from two stockpiles of the harbor site of the Port of Barcelona.. In order to determine possible contaminant components, exhaustive sampling was carried out according to the UNE-EN 932-1 specification. The results are given in the Fig 2.2.

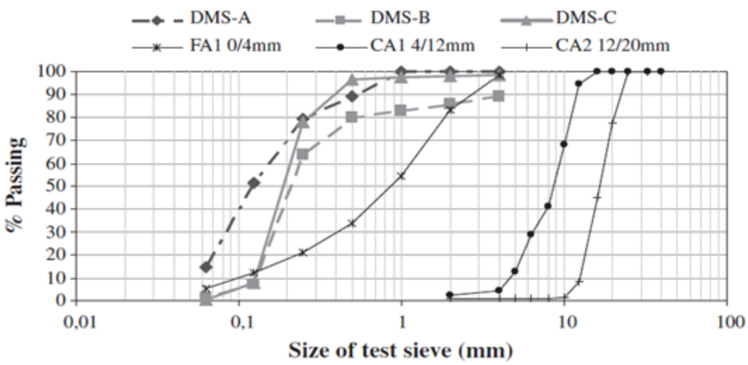

Figure 2.2: Grading curves of aggregates

Hafiz [12]had tested the sample of Sea sand (DMS) extracted from the Dungun, Beach at Terengganu and the results for the grading of that sample is shown in Fig 2.3. The abundant sea sand has been sieved by Sieve Analysis of Fine and Coarse Aggregate is based on ASTM C 136 - 05.

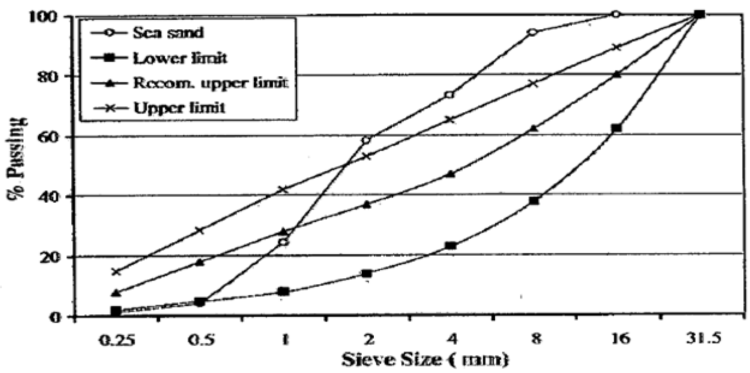

Figure 2.3: Sieve analysis results of fine aggregate

Dias et al. [3]described the shell contents in the offshore sand which has been taken from North of Colombo, Sri Lanka. The fine aggregate grading tests were carried out as per BS 812-103.1: 1985(2000). For the offshore sand samples, the shell content was obtained separately for the aggregate fractions greater than and less than 5 mm, using a hand picking method for the former and dissolving in HCl for the latter. The shell content was measured for coarse, medium, fine and typical grading of offshore sand, from a sample size of 1000 g.

Grading of the fine aggregate and the shell contents (%) in offshore sand are given in Table 2.1 and Table 2.2 respectively.

Table 2.1: Grading of offshore sand

Characteristic	Offshore sand types			
	Typical	Coarse	Medium	Fine
<0.60 mm (%)	44	42	49	85
<0.15 mm (%)	2.6	2.5	2.7	12
D_{50} (mm)	0.63	0.66	0.60	0.21

Table 2.2: Shell contents (%) in offshore sand

Grading	Fraction	
	<5 mm	>5 mm
Coarse	9.18	2.12
Medium	7.10	1.55
Fine	13.12	0.64
Typical	7.44	2.84
Limits (BS 882: 1992)	None	8–20

Table 2.1 shows the grading of the offshore sand characterized in test which indicates a high D50 value of 0.6 mm, which makes it very suitable for concrete production and also for quick draining of seawater.Subsequently Table 2.2 describes the shell content of offshore sand which was also within BS 882 limits.

Limeira et al. [2] had given the results of chemical and mineralogical identification in the test results which also give the heavy metals in g/g in DMS samples. Such properties are given in Table 2.3 & 2.4 respectively. Minerals are given in three categories as Major component, Secondary component and Minority components.

Table 2.3: Mineralogical properties of dredged marine sand by X-ray diffraction

Mineral	1	2	3	4	5
Calcite $CaCO_3$	××	××	××	××	××
Quartz SiO_2	×××	×××	×××	×××	×××
Halite NaCl	×				×
Dolomite $MgCa(CO_3)_2$	×	×	×	×	×
Mica Muscovite $KMgAlSi_4O_{10}(OH)_2$	×	×	×	×	×
Albite $NaAlSi_3O_8$	×	×	×	×	×
Sanidina $(Na,K)AlSi_3O_8$		×	×	×	×
Hidrofilita $CaCl_2$	×				×
Orthoclase $KAlSi_3O_8$			×	×	
Carolinian $Al_2Si_2O_5(OH)_4$	×	×	×	×	×
Silvina KCl					×
Relation of maximum intensity picks calcite/quartz	25/100	12/100	25/100	33/100	24/100

Key: ×××, major components; ××, secondary components; ×, minority components or possible.

Table 2.3 shows that DMS samples are having the components Calcite $CaCO_3$ and Quartz SiO_2 as major and secondary component respectively and all other minerals as minority.

Table 2.4: Heavy metals in DMS samples

Heavy metals (μg/g) in DMS samples.

Samples	Cd	Cu	Zn	Cr	Ni	As	Hg	Pb
1	0.08	1.85	22.21	30.43	20.98	3.53	nd	60.26
2	0.08	2.49	31.65	18.61	8.73	3.62	0.01	nd
3	0.07	2.88	23.9	29.64	12.17	3.57	0.02	114.28
4	0.07	4.12	27.29	35.93	12.38	3.4	0.02	101.98
5	0.01	8.24	26.3	34.2	8.65	3.4	0.06	89.01
Level of action 1	1	100	500	200	100	80	0.6	120

Rodica and Lupinca [14] had investigated the mineralogical properties of the river sand from the Timis river. The properties are given in Table 2.5.

The above Table 2.5 concludes that the content of leachate parts of the sand from Timis is under 1.5%. The content of SiO2 smaller than 90% of the sand situates it in the category of weak sands. And also the total content of Quartz and Feldspar should be more than 90% which is not the case here for this river sand.

Basack and Purkayastha [8] determined the engineering properties of the marine clay collected from Visakhapatnam, India. In the investigation physical, chemical and mineralogical properties were determined. And they have given the Sp. Gravity of marine clay which was 2.62.

Table 2.5: Mineralogical properties of river sand of Timis river

Mineralogical composition	%
A. Basic constitutive materials	
Quartz (SiO_2) (metamorphic + magnetic, rolled) Partially colonized	80
Feldspar ($KAlSi_3O_8$,$NaAlSi_3O_8$)	3
Muscovite KAl_2 $(OH_3F)_2(AlSi_3O_{10})$	5
Garnet-Almandine $Fe_3Al_2(SiO_4)_3$	
Spessartine $(Mn,Fe)_3Al_2(SiO_4)_3$	3
B . Secondary materials	
Biotite, partially with chloride $K(Mg,Fe,Mn)_3(OH_3F)_2AlSi_3O_{10}$	2
Chlorite $(Mg,Al)_3OH_2(AlSi_3O_{10})Mg_6(OH)_6$	1
Magnetite (Fe_3O_4)	2
Ilmenite ($FeTiO_3$)	1
Apatite $CaF(PO_4)_3$	0,5
Titan $CaTi(SiO_3)$	0,5
Rutile (TiO_2)	0,3
Tourmaline $NaFe_3Al_6(OH)_4(BO_3)_3Si_6O_{13}$	0,5
Hornblende	0,5
Zircon Zr $(SiO)_4$	0,2
Cyanide Al_2 (SiO_3)	0,5

2.2.2 Fresh Concrete

Limeira et al. [1] had given the results of slump test of different concrete mixes. The details of concrete mixes taken in experiment and their slump test results in cm are given in the Table 2.6. Slump test was performed as per UNE-EN 83-313-90 standard.

Table 2.6 indicates that the fresh properties of the concretes using DMS in partial substitution of raw sand 0/4 mm were similar to those of the control mixture, with the dry consistency required for the design of concrete pavements.

Table 2.6: Slump test results

Concrete	Nomenclature	Slump (cm)
Reference concrete	RC	1.0
Concrete with 15% DMS-A	CA15%	0.0
Concrete with 25% DMS-B	CB25%	1.0
Concrete with 35% DMS-B	CB35%	3.0
Concrete with 35% DMS-B	CB50%	1.5
Concrete with 25% DMS-C	CC25%	2.0
Concrete with 35% DMS-C	CC35%	1.5
Concrete with 50% DMS-C	CC50%	1.5

Limeira et al. [2] had done experiment based on three different sections of a harbor pavement made with three different concretes. The three concretes were produced at a homologated plant (UNILAND): C1 (control concrete), C2 (concrete made with DMS as corrective fine sand) and C3 (concrete made with DMS as corrective fine sand and reinforced with plastic fibers PF).The slump test (by Abrams cone) was carried out at casing time for the construction of pavements. The results of slump test are given in Table 2.7.

Table 2.7: Slump test results of concrete for pavement

Concrete mix	Slump (cm)
C1	17
C2	22
C3	19

The results of slump test in the experiment shows that the properties of fresh concrete using DMS in substitution of fine sand i.e. C2 and C3, were similar to those of control concrete C1. An acceptable fresh concrete consistency was achieved in both cases.

Wang et al. [13] had examined the durability of self-consolidating lightweight aggregate concrete (SCLAC) made from dredged silt from reservoirs in South Taiwan. The slump test was done to determine the property of fresh concrete. The results were taken for freshly cast concrete i.e. initial slump and reading after 60 minutes. The results are shown in Table 2.8.

Table 2.8: Results of initial slump and slump after 60 minutes

Initial slump (cm)	Slump after 60 minutes (cm)
26-27	51-58

The results of slump test in Table 2.8 shows that fresh self-consolidating lightweight aggregate concrete can meet the requirements of high flowability and slumping time, depending on the concrete. Slump and slump flow of SCLAC reaches 26-27 cm and 51-58 cm, respectively.

2.2.3 Hardened concrete

Limeira et al. [2] described three experimental sections of a harbor pavement made with three different concretes. Fine aggregate which was used in the experiment was extracted from Port of Sant Carles de la Rpita (Tarragona, Spain). Concrete grade which was considered was M30. Three different mixes were considered in the investigation which are C1 (control concrete), C2 (concrete made with DMS as corrective fine sand) and C3 (concrete made with DMS as corrective fine sand and reinforced with plastic fibers PF).The properties of the test specimens were determined after 28 days of moist curing of all the specimens. The results of mechanical properties i.e. compressive strength are given in the Table 2.9.

Table 2.9: Mechanical properties of all concrete mixes after 28 days for M30 grade

Concrete	Compressive strength (MPa)
C1	39 (5%)
C2	36 (4%)
C3	33 (5%)

The results of mechanical properties show that the mechanical properties (compressive strength) of concretes made with DMS in substitution of fine sand i.e. C2 and C3 were nearly similar to those in the control concrete. Concrete C3 made with DMS in substitution of fine sand and PF incorporation obtained lower mechanical properties than the control concrete at 28 days of curing. This effect can be attributed to the higher plasticizer content and the presence of polypropylene fibers.

Agullo et al. [1] studied the mechanical and durability properties of concretes fabricated with dredged marine sand (DMS) as a fine granular corrector in partial substitution of raw sand (from 15% to up to 50% by raw sand mass) designed for harbor pavements. Three fractions of crushed limestone raw aggregates were considered i.e. fine aggregate FA1 0/4 mm, coarse aggregate CA1 4/12 mm and CA2 12/20 mm. Three DMS from the Port of Barcelona were used in partial substitution of FA1. Details of concrete mixes are given in Table 2.6. Concrete mix proportions are given in Table 2.10 and Mechanical properties of all concrete mixes are given in Table 2.11.

Table 2.10: Concrete mix proportion of all concrete mixes

	RC	CA15%	CB25/CC25%	CB35/CC35%	CB50/CC50%
CA2 12/20 mm (kg)	755	755	755	755	755
CA1 4/12 mm (kg)	243	243	243	243	243
FA1 0/4 mm (kg)	896	762	672	582	448
DMS (kg)	0	134	224	314	448
Cement (kg)	329	329	329	329	329
Water (kg)	145	145	145	145	145
Plasticizer (% of cement weight)	0.6	2.6	1.5	2.3	2.6

Table 2.11: Mechanical properties i.e. compressive strength of all concrete mixes

	7 days	28 days
RC	32	35
CA15%	30	33
CB25%	30	35
CB35%	31	40
CB50%	37	39
CC25%	30	41
CC35%	31	38
CC50%	35	40

Mechanical properties i.e. compressive strength and physical properties of the concretes made with DMS in substitution of crushed limestone sand were similar to those of the reference concrete RC. The results also indicate slight increase in compressive strength of concrete CC25% after 28 days as compared to other concrete mixes.

Dias et al. [3] performed the experiment using offshore sand for the reinforced concrete. The offshore sand has been taken from North of Colombo, Sri Lanka and 5 km to 10 km off the Western Coast of Sri Lanka. The results were described about the mechanical and durability properties of the reinforced concrete in this research work. Type of cement which was used in manufacturing work of the concrete was ordinary portland cement. The offshore sand used as a fine aggregate in concrete was having different chloride contents for three concrete grades which are given in Table 2.12.

Table 2.12: Chloride content for all concrete grades

Grade of concrete	Chloride content
20	0.076
25	0.086
30	0.096

Mechanical properties i.e. compressive strength of the concrete with concrete mix proportion is shown in Table 2.13. This table also shows the properties of fresh concrete i.e. measured slump for all concrete grades.

Table 2.13: Concrete mix proportions and results of compression test of all mixes

Grade	20	25	30
Target mean strength (N/mm^2)	30	35	40
Water/cement ratio	0.65	0.59	0.54
Cement content (kg/m^3)	300	339 (331)	361
Water content (kg/m^3)	195	200 (195)	195
Fine aggregate (kg/m^3)	877	837 (843)	814
Coarse aggregate (kg/m^3)	1031	1027 (1031)	1035
Pozzolith 300R (ml/m^3)	900	1017 (993)	1083
Sand/cement ratio	2.92	2.47 (2.55)	2.25
Measured slump (mm)	135	190	130
3 day Strength (N/mm^2)	20	23	26
7 day Strength (N/mm^2)	26	30	33
28 day Strength (N/mm^2)	32	36	39

2.2.4 Durability of concrete

Etxeberria et al. [2] suggested the use of DMS in the harbor pavement construction for three concrete mixes. DMS was extracted from Port of Sant Carles de la Rpita (Tarragona, Spain). Three concrete mixes were C1 (control concrete), C2 (concrete made with DMS as corrective fine sand) and C3 (concrete made with DMS as corrective fine sand and reinforced with plastic fibers PF). These C1, C2 and C3 show the actual specimens. Three cylindrical cores T1, T2 and T3 of 100 mm diameter and 200 mm height were also taken from the specimens and sent for the durability tests.The capillary suction curves of T1, T2 and T3 are illustrated in Fig 2.4 and the corresponding absorption coefficients as well as results of water absorption (%) are summarized in Table 2.14.

Table 2.14: Results of capillary absorption test and water absorption test for all concrete mixes

Concrete mix	Capillary absorption coefficient (cm/h$^{1/2}$)	Absorption (%)
C1	0.0441	-
C2	0.0558	-
C3	0.0632	-
T1	0.0274	5.9
T2	0.023	5.5
T3	0.0236	5.6

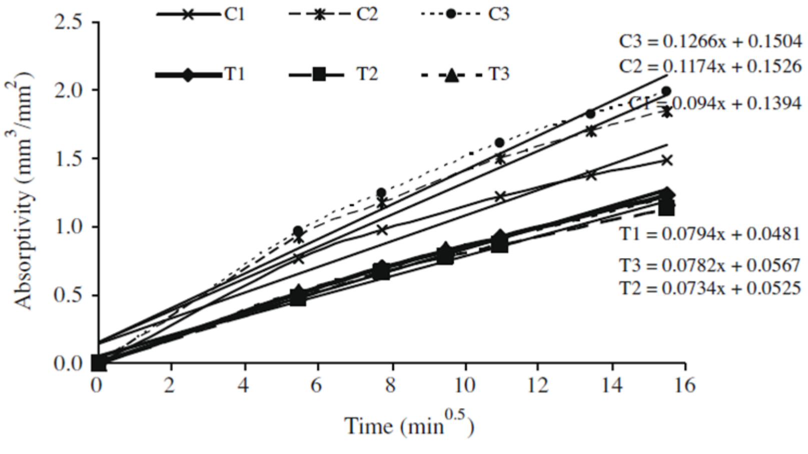

Figure 2.4: Capillary suction curves in the first 4 hrs for C1, C2 and C3 specimens and T1, T2 and T3 cylindrical cores

The results of the experiment show that the concrete made with DMS i.e. C2 and C3 show the higher values of capillary absorption coefficient for the results related with test specimens, whereas the results for the same test are low for cylindrical cores. Absorption (%) for cylindrical cores less for C2 as compared with the concrete mix C3 and C1.

Limeira et al. [1] studied the different durability parameters of concrete using DMS of different dosage varies from 15% to 50% replacement of river sand with DMS. Three types of DMS materials in partial substitution of crushed limestone raw sand were used in the investigation. Table 2.6 shows the details of all concrete mixes. Sorptivity test was done in the experimental work and following Table 2.15 and Fig 2.5 show the results of sorptivity test. DMS-A sample was discarded because the Cl^- content was exceeding the limit in this sample.

Table 2.15: Sorptivity test results

Concrete mix	Sorptivity (mm/min$^{1/2}$)
RC	0.060
CB35%	0.059
CB50%	0.058
CC35%	0.046
CC50%	0.056

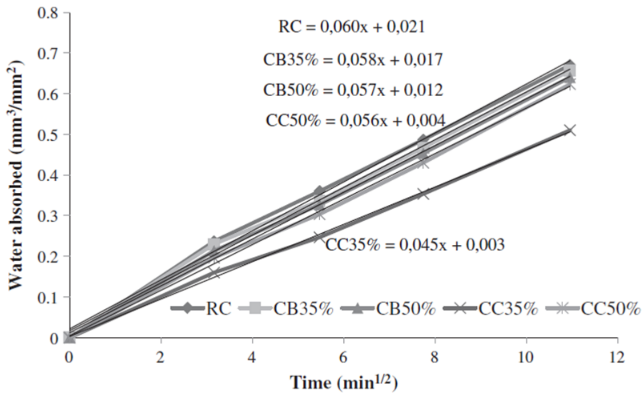

Figure 2.5: Capillary suction curves in concrete mixes in first 2 hrs

For all concrete mixes, the results with respect to sorptivity test were maintained. But mix CC35% had shown slight lesser value as compared to other concrete mixes.

Dias et al. [3] have done an experiment on the offshore sand in reinforced concrete and the accelerated corrosion test was performed for grade 20 concrete i.e. the most critical structural grade. This grade was taken because it is the lowest grade used in practice for structural concrete and would have the greatest sand content. Hence the greatest effects of corrosion would be found in grade 20 concrete.

Four specially fabricated 150 mm cube moulds were used so that two mild steel bars of 10 mm diameter could be embedded in each cube. The bars were machined down to 10 mm from a nominal 12 mm diameter. After being weighed, these bars were inserted at two corners of the cubes so that a cover of 20 mm was maintained to two of the cube faces. Fig 2.6 shows the details of the specimen. The moulds had a base plate with two holes into which the bars were inserted and also an arrangement to locate the bars at the top. After 1 day of casting and again 1 day of drying, the part of the bar which is outside of specimen at top and bottom, were coated with epoxy as shown in Fig 2.6.

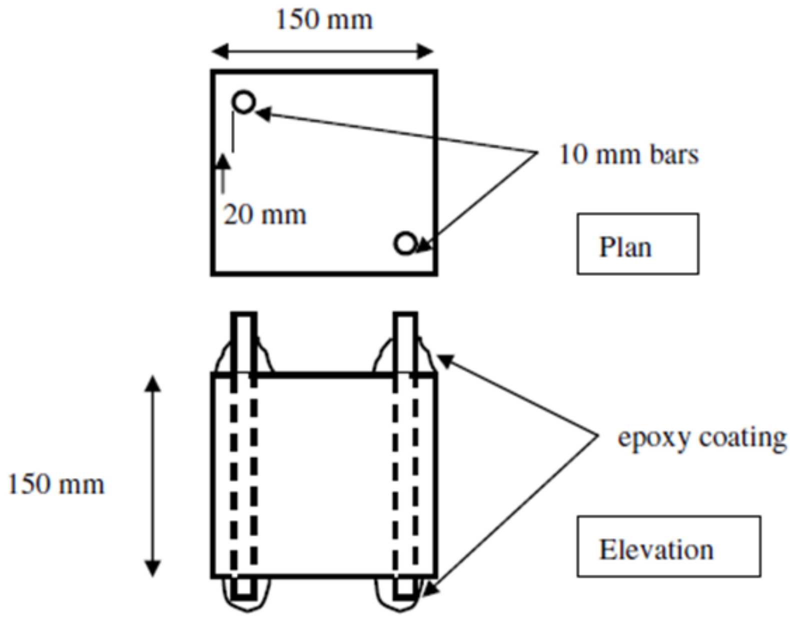

Figure 2.6: Accelerated corrosion test specimen

Two of the specimens were left to dry until an age of 14 days, after which they were placed in a carbonation chamber that was initially filled with CO_2 and subsequently re-filled each time the chamber was opened to take half-cell potential readings. The other two were cured in a water bath until an age of 14 days and then immersed to roughly half their height in a 5% NaCl solution.

Half-cell potential readings were measured at the top, middle and bottom of each specimen initially at weekly interval for the specimen in carbonation chamber and twice weekly for specimens in NaCl solution.

The results of the half-cell potential for the specimen in NaCl bath are given in Fig. 2.7 and for specimens in carbonation chamber (100% CO_2) are given in Fig 2.8.

The average percentage weight loss in embedded reinforcing bars is shown in Fig 2.9.

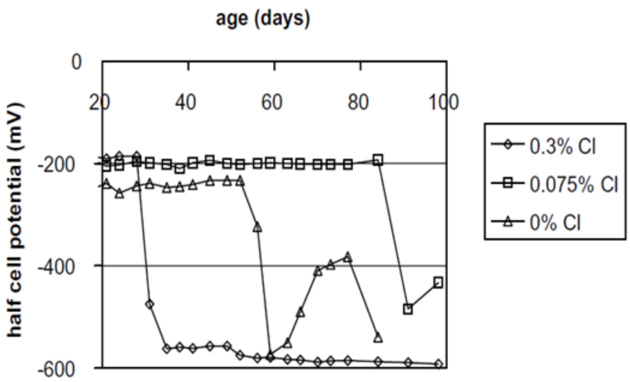

Figure 2.7: Half-cell potential readings for specimens in NaCl bath

In Fig 2.7 three different mixes were considered i.e. concrete with sand having allowable Cl^- content of 0.075%, concrete mix with sea-water saturated sand having Cl^- content of 0.3% and concrete mix free from Cl^- content.

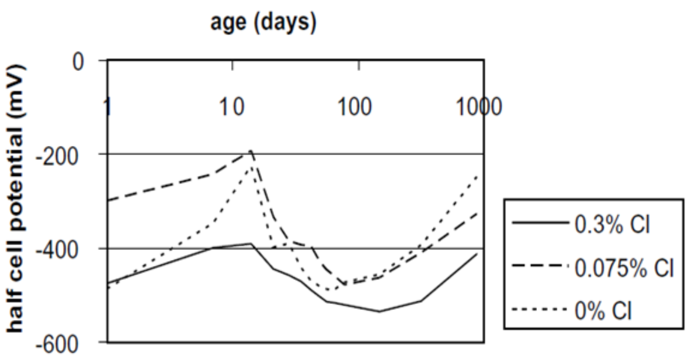

Figure 2.8: Half-cell potential for specimens in carbonation chamber (100% CO_2)

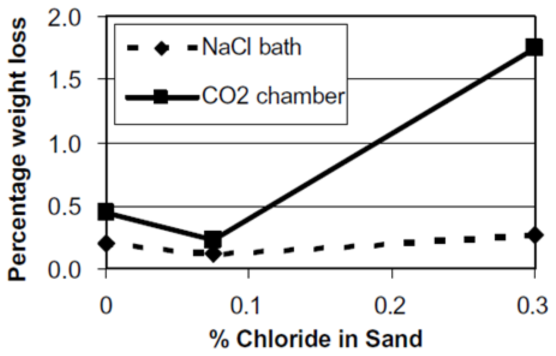

Figure 2.9: Average percentage weight loss in the embedded bars

The corrosion performance concrete mix with the allowable Cl^- content of 0.075% in the sand is satisfactory and similar to a chloride free control mix; on the other hand, a mix with 0.3% Cl^- in the sand shows clear evidence of significant corrosion in embedded steel.

2.3 Applications

Marine sands are the finer fractions of the aggregate deposits found on the inner continental shelf off the UK coast. Marine sands have mechanical, chemical and physical properties identical to the high quality land-based sands and as such the end uses are no different. They are also widely used in the production of: [17]

1. Mortar for bricklaying and blockmaking
2. Screeds
3. External renders
4. Internal rendering

5. Masonry blocks

6. Paving blocks

Application of marine sand related with the nourishment of the beaches and shorelines are very often in Ostia (Rome). In Fig 2.10, some phases of the nourishment work of shorelines in Ostia (Rome) are shown using marine sand.[18]

Figure 2.10: Phases of nourishment of shorelines in Ostia (Rome)

Other important applications which are done in Ostia (Rome) are as follows:

- National parks and blue oases
- Areas for the dumping of harbor materials
- Cables and pipes
- Offshore terminals which are not permitted for anchorage and fishing
- Artificial barriers and military shooting-range, as well as the belt within 3 nautical miles away of the coastline
- Intertidal feeding / creation, e.g. islands for birds, mudflat and salt marsh creation, fisheries habitat and wetland restoration.

EMSAGG seminar at Turkish chamber of shipping at Bob dean university of Florida had discussed about the engineering use of marine sand in coastal projects. They proposed the use of marine sand as follows.[15]

- Offshore environment such as corals, fish, reefs etc.
- Onshore environment such as increase and/or redistribute wave energy.
- Construction: concrete roads and landfills
- Manufacturing glass and other products
- Beach nourishment

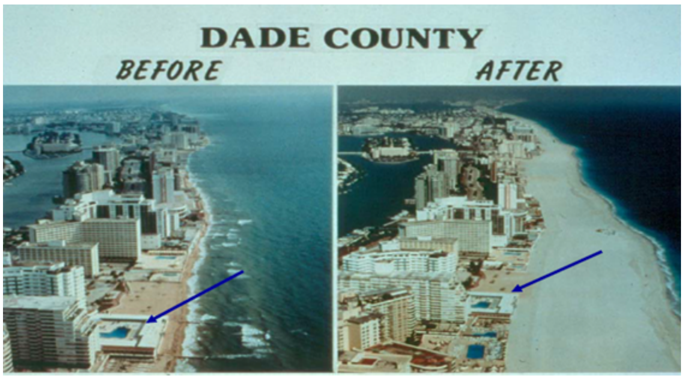

Figure 2.11: The Beach nourishment: 1976-1981

Fig 2.12 and 2.13 show the images of Miami beaches before and after nourishment using marine sand

Figure 2.12: Miami beach before nourishment

Figure 2.13: Miami beach after nourishment

Dias et al. [3] reported the experiment on offshore sand for reinforced concrete. They explained about the economic aspects of offshore sand in the concrete. In that they suggested to use offshore sand as a viable alternative of river sand in manufacturing of concrete. Because offshore sand extracted from below around 15 m of ocean depth (i.e. beyond the surf zone) would not affect the coastal sediment budget. It has been found that the dredging and pumping costs would be around 90% of the stockpiled sand cost; transport costs from the stockpile would not be excessive as the sand is meant to service the construction boom in the commercial capital of Colombo, which is just 15 km away.

2.4 Summary

The chapter deals with the basic overview of research work which was done in the past with respect to dredged marine sand as a viable replacement of river sand in concrete and showed decent results when used in concrete & tested for concrete's mechanical and durability properties such as compressive strength and water absorption, sorptivity & accelerated corrosion test respectively.

Chapter 3

Experimental work

3.1 General

The chapter describes the material properties which have been used in concrete as a fine aggregate i.e. dredged marine sand and natural river sand, coarse aggregates and super plasticizer. Further concrete mix proportion, methods followed for the casting and curing of the concrete specimens are given. Different types of tests with their procedures are explained in detail in this chapter.

3.2 Materials

Details about various ingredients of the concrete such as types of cement, fine aggregate, coarse aggregate, super plasticizer etc. are as follows.

3.2.1 Aggregates

Cement which is used for the casting work is 53 grade OPC. The physical properties of cement are shown in Table 3.1. Aggregates are procured locally for the casting work of concrete specimens. The aggregates are tested for their properties in accordance with the IS standards. Locally available river sand is used as a fine aggregate for concrete. Also locally available coarse aggregates of two grades are used in the concrete i.e. 10 mm and 20 mm. The sieve analysis of the fine aggregate is performed as per IS 2386 (1963) part-1.[25]

Table 3.1: Physical properties of cement

Properties	Results achieved	Specification in IS 12269:1987 for 53 grade OPC
Fineness in m^2/kg	351	Min. 225
Soundness by Le chatelier method in mm	0.4	Max. 10
Initial setting time in minutes	35	Min. 30
Final setting time in minutes	240	Max. 600
3 days compressive strength in MPa	28.75	Min. 27
7 days compressive strength in MPa	39.85	Min. 37
28 days compressive strength in MPa	54.47	Min. 53

The sieve analysis results are shown in Table 3.2 for natural river sand. To determine fineness modulus and zone of the sand the tests are conducted.

Table 3.2: Sieve analysis results of natural river sand

Sieve Size	Mass retained (grams)	% mass retained	Cumulative % of mass retained	Cumulative % of passing
4.75 mm	40	4	4	96
2.36 mm	227	22.7	26.7	73.3
1.18 mm	35	3.5	30.2	69.8
600 μm	144	14.4	44.6	55.4
300 μm	308	30.8	75.4	24.6
150 μm	165	16.5	91.9	8.1
Below 150 μm	81	8.1	-	0
Total	1000	100	268.8	-

Test performed for determining the specific gravity for natural river sand. Results of these parameters for natural river sand are given in Table 3.3.

Table 3.3: Results for various parameters of natural river sand

Type of Sand	Parameter	Result
Natural river sand	Fineness modulus	2.68
Natural river sand	Zone	2
Natural river sand	Specific gravity	2.6

Sieve analysis results for coarse aggregate of 10 mm and 20 mm are presented in Table 3.4 and Table 3.5 respectively.

Table 3.4: Sieve analysis results for 10 mm aggregate

Sieve Size	Mass retained (grams)	% mass retained	Cumulative % of mass retained	Cumulative % of passing
80 mm	0.0	0.0	0.0	100.0
40 mm	0.0	0.0	0.0	100.0
20 mm	0.0	0.0	0.0	100.0
10 mm	46.0	4.6	4.6	95.4
4.75 mm	875.0	87.5	92.1	7.9
2.36 mm	39.0	3.9	100.0	0.0
1.18 mm	0.0	0.0	100.0	0.0
600 µm	0.0	0.0	100.0	0.0
300 µm	0.0	0.0	100.0	0.0
150 µm	0.0	0.0	100.0	0.0
Below 150 µm	0.0	0.0	-	0.0
Total	1000	100		
Fineness modulus = 596.7/100 = 5.967				

Table 3.5: Sieve analysis results for 20 mm aggregate

Sieve Size	Mass retained (grams)	% mass retained	Cumulative % of mass retained	Cumulative % of passing
80 mm	0.0	0.0	0.0	100.0
40 mm	0.0	0.0	0.0	100.0
20 mm	660.0	33.0	33.0	67.0
10 mm	1270.0	63.5	96.5	3.5
4.75 mm	70.0	3.5	100.0	0.0
2.36 mm	0.0	0.0	100.0	0.0
1.18 mm	0.0	0.0	100.0	0.0
600 μm	0.0	0.0	100.0	0.0
300 μm	0.0	0.0	100.0	0.0
150 μm	0.0	0.0	100.0	0.0
Below 150 μm	0.0	0.0	-	0.0
Total	2000	100	729.5	
Fineness modulus = 729.5/100 = 7.295				

3.2.2 Super plasticizer

There are two different concrete grades which were considered in the experimental work i.e. M25 and M40. For M40 concrete grade, super plasticizer has been used for achieving required workability of the concrete. Fosroc Conplast SP 430 was used as an admixture to improve workability of the fresh concrete.

3.3 Properties of Marine sand

3.3.1 Physical properties of dredged marine sand

The test is performed to determine the fineness modulus and zone of the dredged marine sand. Results are given in Table 3.6 and Table 3.7 respectively.

Table 3.6: Sieve analysis results of the dredged marine sand

Sieve Size	Mass retained (grams)	% of mass retained	Cumulative % of mass retained	Cumulative % of passing
4.75 mm	0	0	0	100
2.36 mm	44	4.4	4.4	95.6
1.18 mm	121	12.1	16.5	83.5
600 µ	276	27.6	44.1	55.9
300µ	516	51.6	95.7	4.3
150µ	27	2.7	98.4	1.6
Below 150µ	16	1.6	-	0
Total	1000	100	259.1	-

Table 3.7: Results for various parameters for dredged marine sand

Type of Sand	Parameter	Result
Dredged marine sand	Fineness modulus	2.59
Dredged marine sand	Zone	2
Dredged marine sand	Specific gravity	2.56

3.3.2 Chemical properties of marine sand

The chemical properties of marine sand are investigated by two other laboratories and results are presented in Table 3.8, 3.9 and 3.10 respectively. Sample taken for test = 35 kg, Moisture condition when received = Surface dry.

Table 3.8: Chemical analysis results provided by Geo Test house

Sr. no.	Test name	Test method	Test result	Specification requirement (IS 383-1970)
1	Organic content	IS 2386 : Part-2 Cl-6.0	Not detected	-
2	Chloride (%)	B.S. 812 : P-117	0.034	Max 0.04%
3	Sulfur as SO_3 (%)	B.S. 812 : P-118	0.794	Max 0.05%
4	Presence of deleterious material (%)	IS 2386 : P-2 Cl-2 & 3	6.847	Max 5%
5	Volatile solids	IS 3025 : P-18	0.084	-

Table 3.9: Results of chemical analysis related with Alkali aggregate reactivity provided by K.C.T. Consultancy Services

No.	Alkali aggregate reactivity test	Fine aggregate
1	Reduction in alkalinity (milimol / l)	132.19
2	Silica dissolved from 300 µm size aggregate material (milimol / l)	1.78

Table 3.10: Results of chemical test for deleterious material of marine sand provided by K.C.T. Consultancy Services

No.	Test description	Results (%)	Requirement as per IS 383 (%)
1	Coal and Lignite	Nil	Max 1%
2	Clay lumps	Nil	Max 1%
3	Material finer than75 µ	1.5	Max 3%
4	Shale	6.60	Max 1%
5	Total % of all deleterious material	8.10	Max 5%

3.4 Concrete mix design

The concrete mix proportioning using dredged marine sand is not different than the usual mix design of concrete using natural river sand. All the constituents are same for both the cases i.e. concrete using dredged marine sand and natural river sand. The mix design is done based on provisions of IS 10262 (2009). [19]

The w/c ratio is selected 0.5 for M25 grade concrete and 0.4 for M40 grade concrete. For the concrete grade M40, the super plasticizer is added for casting of concrete. The amount of 0.8% of total mass of cement was taken as a super plasticizer for M40 grade concrete. No super plasticizer is used for M25 grade concrete. Table 3.11 presents concrete mix proportioning for both concrete grades and for all concrete mixes respectively.

Table 3.11: Concrete mix proportion for all concrete mixes

Grade of concrete	w/c ratio	Water content (kg/m^3)	Cement Content (kg/m^3)	Fine Aggregate (kg/m^3)	20 mm aggregate (kg/m^3)	10 mm aggregate (kg/m^3)
M25	0.5	191.8	383.16	630.47	733.15	488.78
M40	0.4	143.8	359.22	599.88	761.67	507.78

3.5 Casting of Concrete

This process plays very vital role with respect to all properties of fresh as well as hardened concrete. First of all weighing and batching process of all ingredients of concrete i.e. cement, fine aggregate and coarse aggregate i.e. 10 mm and 20 mm, water and super plasticizer is to be done with higher accuracy before starting the mixing process. Dry mix is to be made in the pan mixer for 20 to 30 seconds to make the consistent mix by mixing only fine and coarse aggregate first. Cement is added to this mix and after that mixing is started and gradually water is added in the mix. Moulds of the specimens are made ready for pouring the fresh concrete in it by applying proper lubricant as shown in Fig 3.1.

Figure 3.1: Moulds for concrete specimens

The mixing of concrete is performed using Pan mixer as shown in Fig 3.2. The mixing process for all the mixes is same as conventional mixing method. The mixing is continued for 3 to 4 minutes. For the concrete grade M40, the chemical admixture i.e. super plasticizer is to be added to the water prior to adding in the concrete mix. The concrete is immediately poured into the moulds of specimens in three layers. Each layer of concrete mix is compacted using 20 mm rod with 25 to 35 manual strokes. The concrete mix is vibrated further until specified condition is attained using table vibrator which is shown in Fig 3.3.

Figure 3.2: Pan mixer for mixing of concrete

Figure 3.3: Table vibrator for compacting concrete mix

After compaction of concrete, the top surface is leveled using trowel and also the sides of mould are struck by using hammer in order to expel air if any present inside the concrete and to make the sides smoothened. The rest period is same as in case of conventional concrete i.e. 24 hour 1/2 hour as per IS 516 (1959).[20] The curing period is decided 7, 28 and 56 days for determining the mechanical properties i.e. compressive strength of plain concrete specimens. For durability aspects 28 days of curing period is done for all specimens i.e. plain and RC specimens. Curing of plain concrete specimens and RC specimens are shown in Fig 3.4 and 3.5 respectively.

Figure 3.4: Curing of plain concrete specimens

Figure 3.5: Curing of RC specimens

3.6 Different types of tests

Different types of tests are performed to determine mechanical and durability properties of the hardened concrete. Compressive strength of plain concrete is considered. For durability properties such as sulfate resistance test, acid resistance test, chloride resistance test, water absorption test, sorptivity test plain concrete specimens are taken and for accelerated corrosion test, RC specimens are taken.

3.6.1 Mechanical properties

The mechanical properties of hardened concrete are determined after performing compression test on plain concrete specimens. The compression test is done using 2000 kN capacity hydraulic testing machine. Compressive strength is determined after testing plain concrete cubes of dimension 150 mm X 150 mm X 150 mm as per IS 516 (1959).[20] Fig 3.6 shows plain concrete specimen which is being tested in compression testing machine.

Figure 3.6: Plain concrete cube in compression testing machine

For evaluating the compressive strength of concrete cubes, following Eq 3.1 is used.

$$Compressive\ strength\ of\ concrete\ (N/mm^2) \quad = \quad P/A \tag{3.1}$$

Where P = Failure load in N

A = Area of concrete specimen in mm^2 (150 mm X 150 mm)

3.6.2 Acid resistance test

The plain concrete specimens are exposed in the acid tank for required ages in months. After completion of exposure, the specimens are taken out of the acid tank. The required exposure ages considered for plain concrete specimens are 3 months, 6 months and 12 months respectively.

The acid which is used for the test is Sulfuric acid (H_2SO_4) solution having 5% concentration by volume of water. [22] The solution is stirred every week and pH value of solution is measured after every 15 days. Modification in the pH is done by adding acid or water in the tank if pH value differs from 1. Fig. 3.7 and 3.8 show acid tank with concrete specimens for acid exposure and digital pH measuring device respectively.

Figure 3.7: Tank of acid solution with concrete specimen

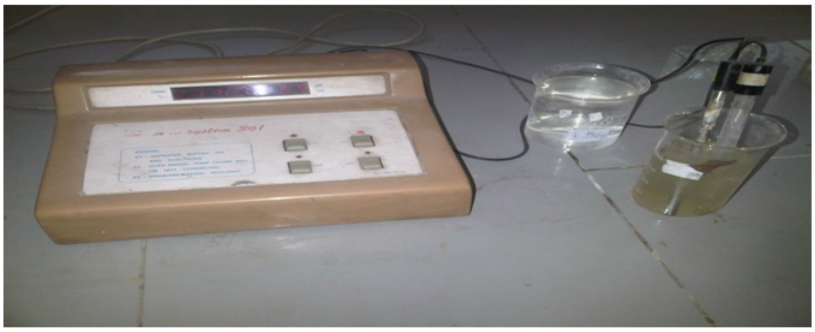

Figure 3.8: Digital pH measuring device

All the specimens are weighed before keeping them into the acid tank. After removing from the tank of acid solution after completion of exposure, respective specimens are wiped clean and weighed. This weight is considered as a final weight of concrete specimens in kg. Change in mass of concrete specimens after completion of exposure of corresponding age is evaluated. For evaluating the change in compression strength of concrete specimen after completion of exposure age in acid, the specimens are kept in saturated surface dry (SSD) condition.

Details of acid exposure test parameters are given in Table 3.12. The concrete specimen size is 150 mm X 150 mm X 150 mm for this test. They are studied and comparison between all concrete mixes is to be evaluated after completion of exposure in acid solution at corresponding time duration.

Table 3.12: Details of acid resistance test

Parameters to study	Unit	Acid solution concentration	Exposure age in months	Total no. of concrete cubes
Change in compressive strength	MPa	5%	3, 6 and 12	108
Change in mass	kg	5%	3,6 and 12	

3.6.3 Sulfate resistance test

All the plain concrete specimens are exposed to the sulfate attack for required time duration. After completion of exposure at designated ages, the concrete specimens are taken out of the tank of sulfate solution. The time duration for sulfate exposure, selected for plain concrete specimens is 3 months, 6 months and 12 months respectively.

Sodium sulfate (Na_2SO_4) is used to prepare sulfate solution having 5% concentration by total mass of water. [21] The sodium sulfate powder of required quantity is added to water to make the sulfate solution. The sulfate solution is stirred every week and pH value of is measured after interval of 15 days and modification in the pH is done by adding sodium sulfate powder or water in the tank if pH value differs from 1. Fig.3.9 and 3.10 presents concrete specimens for sulfate exposure and sodium sulfate (Na_2SO_4) powder.

Figure 3.9: Tank of sulfate solution with concrete specimens

Figure 3.10: Sodium sulfate (Na_2SO_4) powder

The concrete specimens are weighed prior to keep them into the sulfate solution. After removing them out from the tank after completion of exposure, respective specimens are wiped clean and weighed. This is considered as a final weight of concrete specimens in kg. Change in mass of specimens after completion of respective exposure is determined. For evaluating the change in compressive strength of concrete specimens after completion of designated duration in sulfate solution, the specimens are considered saturated surface dry (SSD) condition. Details of sulfate exposure test parameters are given in Table 3.13. The concrete specimen size is 150 mm X 150 mm X 150 mm for this test. They are studied and comparison between all concrete mixes is to be evaluated after completion of exposure in sulfate solution at corresponding time duration.

Table 3.13: Details of sulfate resistance test

Parameters to study	Unit	Sulfate solution concentration	Exposure ages in months	Total no. of concrete cubes
Change in compressive strength	MPa	5%	3, 6 and 12	108
Change in mass	kg	5%	3,6 and 12	
Pulse velocity by UPV test	m/s	5%	3,6 and 12	

3.6.4 Chloride resistance test

All the plain concrete specimens are exposed to the chloride attack for required time duration. After completion of the exposure at designated age, the concrete specimens are taken out of the tank of chloride solution. The time duration for chloride exposure selected for plain concrete specimens is 2 months.

Sodium chloride (NaCl) is used to prepare chloride solution having 3% concentration by total mass of water. The sodium chloride powder of required quantity is added to water to make chloride solution. The solution is stirred every week and pH value is measured after interval of 15 days and modification in the pH is done by adding sodium chloride powder or water in the tank if pH value differs from 1. Fig. 3.11 and 3.12 present tank of chloride solution with concrete specimens and sodium chloride (NaCl).

Figure 3.11: Tank of chloride solution with concrete specimens

Figure 3.12: Sodium chloride (NaCl) powder

Details of chloride exposure test parameters are given in Table 3.14. The concrete specimen size which was decided is 150 mm X 150 mm X 150 mm for this test. They are studied and comparison between all concrete mixes is to be evaluated after completion of exposure in chloride solution at corresponding time duration.

Table 3.14: Details of chloride resistance test

Parameters to study	Unit	Chloride solution concentration	Exposure ages in months	Total no. of concrete cubes
Change in compressive strength	MPa	3%	2	36
Change in mass	kg	3%	2	
Pulse velocity by UPV test	m/s	3%	2	

3.6.5 Sorptivity test

Sorptivity is defined as a measure of the capacity of the medium to absorb or desorb liquid by capillarity. Hall (1989) [23] had given the definition of sorptivity that sorptivity is a quantity that measures the unsaturated flow of fluids into the concrete. In simple words sorptivity is defined as the cumulative water absorption per unit area of inflow surface per square root of elapsed time.

The equation for finding the Sorptivity [9] is given as Eq. 3.2.

$$Sorptivity \quad S \quad = \quad i/t^{1/2} \tag{3.2}$$

Where i is the cumulative water absorption per unit area of inflow surface and t is the elapsed time.

For performing this test, first of all the concrete specimens are cured for 28 days.

The concrete specimens are put into the oven for 7 days at 50 C temperature. The specimens are taken out of the oven and weighed. This phenomenon is considered as weight of oven dried cubes in kg. The concrete specimens are sealed using electrician's tape or any appropriate sealing material such as mixture of wax and resin with appropriate proportion. The mixture of wax and resin is taken as a sealing material. The proportion of wax and resin is considered as 60% resin and 40% wax. Both the materials are available in solid form. It is essential to convert them in liquid form. The wax and resin are shown in Fig 3.13. Fig 3.14 shows the hot plate which is used to make both the materials liquid.

Figure 3.13: Materials for sealing the specimens

Figure 3.14: Hot plate with sealing materials

All four sides of concrete specimens are sealed using this mixture upto the height of 15 mm to 20 mm as height of immersion in water for performing the test is 15-20 mm. The initial weight of concrete specimens is measured and is considered as weight of sealed cubes at time equal to 0 seconds. Fig 3.15 shows some of the sealed specimens.

Figure 3.15: Sealed specimens prepared for sorptivity test

The time intervals considered for the test are 1, 2, 3, 4, 5, 9, 12, 16, 20 and 25 minutes, respectively. A bunch of filter papers of approximate thickness of 7 mm to 10 mm is put onto the shallow tray and water is poured upto a height such that after keeping the cube on it, 5-10 mm concrete surface comes in the contact to water as shown in Fig 3.16.

Figure 3.16: Sealed cube on bunch of filter papers for sorptivity test

The weight of the concrete specimen is measured after each time interval and plot of i vs ?t is drawn. The sorptivity is to be determined by measuring slope of the line. Fig 3.17 shows the plot of sorptiviity test.[9]

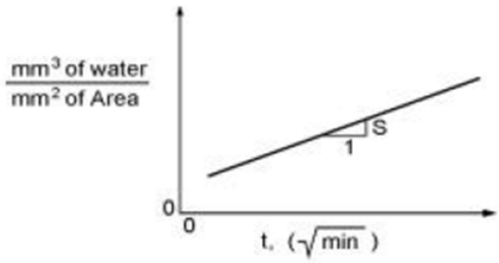

Figure 3.17: Graph for sorptivity test: Stanish[9]

3.6.6 Water absorption test

This test is done to know the relative porosity or permeability characteristics of the concrete. The test is carried out after 28 days of moist curing. The concrete specimens used for this test are 150 mm X 150 mm X 150 mm size cubes. The percentage absorption [6] is calculated using Eq 3.3.

$$Absorption \ \ (\%) \ = \ (w_2 - w_1)/w_1 * 100 \tag{3.3}$$

Where w_1 = weight of concrete specimen after complete drying at 105C
w_2 = final weight of surface dry concrete specimen after immersion in water at least 24 hours

The concrete specimens are first dried for 24 hours at 105C in oven. The concrete specimens are removed from the oven and weighed which is considered as initial weight w_1. They are immersed in water again for 24 hours. Fig 3.18 shows the concrete specimens in water tank. Details of water absorption test parameters are given in Table 3.15.

Figure 3.18: Concrete specimens in water tank for water absorption test

Table 3.15: Details of chloride resistance test

Parameters to study	Unit	Period in oven for complete dry	Duration of immersion in water tank	No. of concrete cubes
Change in mass	kg	24 hours	24 hours	36

Fig 3.19 shows the concrete specimens which are taken out from water tank and kept for some duration to allow specimens for surface drying. After that all specimens are weighed which is considered as final weight w_2 in kg.

Figure 3.19: Specimens in Saturated surface dry (SSD) condition

3.6.7 Accelerated Corrosion test (ACT)

This experiment is related with the RC specimens. Impressed current technique (ICT) is used for conducting the accelerated corrosion test.[7] For the test RC specimens are cast using one HYSD bar of 8 mm diameter to serve as anode. One stainless steel bar of same diameter is inserted in the concrete at the time of casting to serve as cathode for proper circuitry. Specimens are of 150 mm diameter and 300 mm height. Fig 3.20 shows such type of specimens. Average result of three specimens is to be taken as a final result.

Figure 3.20: Specimens for accelerated corrosion test

To protect any structure from adverse effects of corrosion, study of initiation of corrosion in structure is very essential. It is obvious that corrosion is a natural process and takes years to occur in RC structures. Therefore, investigation related to corrosion in limited time duration is conducted to fulfill following objectives.

- To induce corrosion in reinforcement of concrete cylinders.
- To evaluate rate of corrosion with the help of half-cell potentiometer and compare results for all concrete mixes.
- To observe time period for initiation of crack in concrete.

Fig 3.21 shows the test setup for accelerated corrosion test. In the test HYSD bar is connected with positive terminal which serves as an anode and stainless steel bar is to be connected with negative terminal which serves as a cathode.

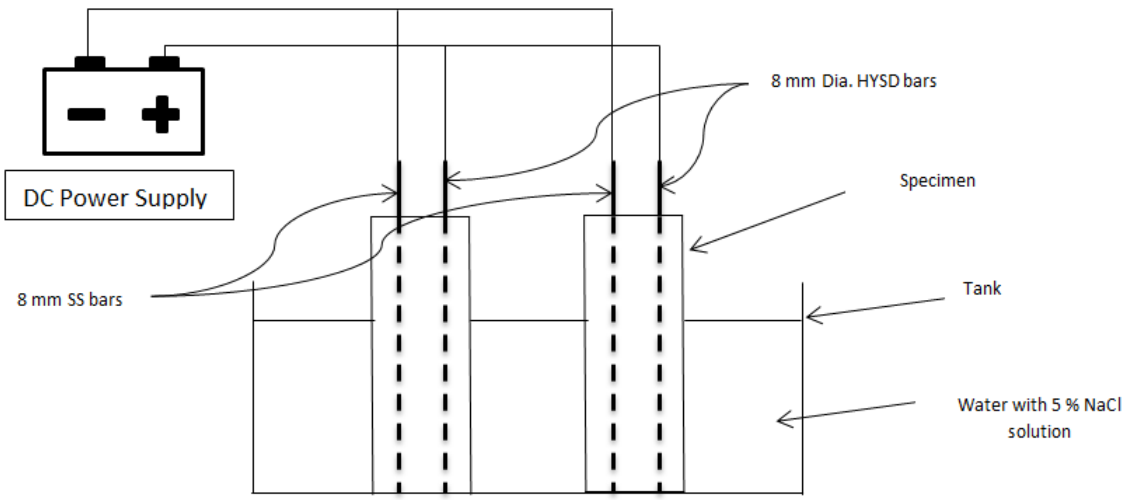

Figure 3.21: ACT test setup

For the test, concrete specimens are to be immersed in the water having 5% NaCl concentration. The water level is adjusted in such a way that approximately 2/3 of height of the specimens come in contact with water. Fig 3.22 and 3.23 shows the concrete specimen kept for ACT in tank of NaCl solution and rectifier which is used for DC power supply, respectively. 9 concrete specimens are put in parallel connection for the test. The voltage is set constant throughout the test i.e. 30 V. Current is measured every day separately for all the specimens in ampere. 12 concrete specimens can also be put in parallel connection for this test at 30 V.

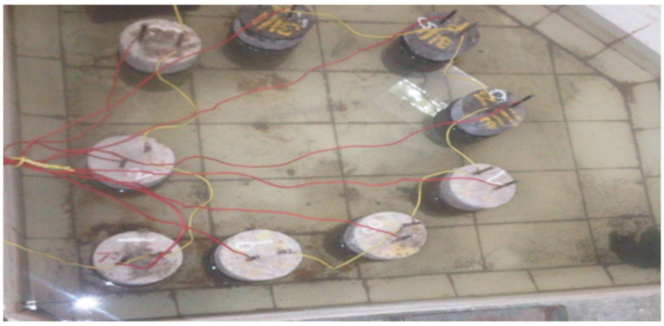

Figure 3.22: Specimens in tank of NaCl solution for ACT before starting of test

Figure 3.23: Rectifier for DC power supply

On observation basis the corrosion in the reinforcement is detected after completion of 1 to 2 weeks. UPV test is used as non-destructive test. Corrosion rate in the reinforcement is measured using half-cell potentiometer before starting of test and after completion of the test in mV as shown in Fig 3.24.

Figure 3.24: Half-cell potentiometer test on RC specimens

Chapter 4

Results and discussion

4.1 General

The chapter contains results of compressive strength after various time duration for all concrete mixes at different ages. The chapter also includes results related to the durability properties such as acid resistance, sulfate resistance, chloride resistance, sorptivity test, water absorption test for concrete mixes. Results of accelerated corrosion test for RC specimens of concrete mixes are included in this chapter.

4.2 Compressive strength

The evaluation of compressive strength of concrete mixes at 7, 28 and 56 days are presented in Table 4.1, 4.2 and 4.3, respectively.

Graphical representation of the comparison of average compressive strength for all concrete mixes for OPC based concrete and PPC based concrete for M25 grade has been presented in Fig 4.1 and 4.2, respectively. For M40 grade, graphical representation of compressive strength for all concrete mixes for OPC based concrete and PPC based concrete has been given in Fig 4.3 and 4.4, respectively.

Table 4.1: Compressive strength of concrete mixes after 7 days

Concrete grade	Type of cement	Mix	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
M25	OPC	A	24	22.67
			22.7	
			21.3	
		B	24.4	23.4
			24	
			21.78	
		C	26.2	27.4
			25.3	
			30.7	
M25	PPC	A	20	19.93
			20.9	
			18.9	
		B	21.8	22.52
			22.2	
			23.6	
		C	20.4	21.19
			21.3	
			21.8	
M40	OPC	A	31.1	32.14
			32	
			33.3	
		B	37.3	37.11
			38.9	
			35.1	
		C	40	42.96
			43.1	
			45.8	
M40	PPC	A	28.9	26.7
			24.4	
			26.7	
		B	27.6	27.7
			28	
			27.6	
		C	28	27.7
			27.6	
			27.6	

Table 4.2: Compressive strength of concrete mixes after 28 days

Concrete grade	Type of cement	Mix	Compressive strength (N/mm²)	Average compressive strength (N/mm²)
M25	OPC	A	36	35.4
			34.7	
			35.6	
		B	42.7	41.6
			40.9	
			41.3	
		C	43.11	43.26
			42.2	
			44.4	
M25	PPC	A	34.7	32.9
			31.1	
			32.9	
		B	31.6	32.9
			34.2	
			32.9	
		C	31.56	33.18
			34.67	
			33.3	
M40	OPC	A	45.8	48.74
			49.8	
			50.7	
		B	53.3	54.07
			55.6	
			53.3	
		C	53.3	54.52
			55.6	
			54.7	
M40	PPC	A	43.11	42.96
			43.56	
			42.2	
		B	48.9	43.11
			40	
			40.4	
		C	47.56	47.4
			46.22	
			48.4	

Table 4.3: Compressive strength of concrete mixes after 56 days

Concrete grade	Type of cement	Mix	Compressive strength (N/mm²)	Average compressive strength (N/mm²)
M25	OPC	A	52.9	48.6
			46.7	
			46.2	
		B	48	49.8
			48.4	
			52.9	
		C	53.3	52.9
			52.4	
			52.9	
M25	PPC	A	40	39.4
			39.6	
			38.7	
		B	43.56	42.37
			41.3	
			42.2	
		C	42.66	43.56
			43.56	
			44.4	
M40	OPC	A	55.6	53.63
			52.4	
			52.9	
		B	54.7	54.07
			53.3	
			54.2	
		C	59.6	58.52
			58.7	
			57.3	
M40	PPC	A	51.1	51.85
			52.4	
			52	
		B	52.4	52.9
			53.3	
			52.9	
		C	52	49.03
			43.56	
			44.9	

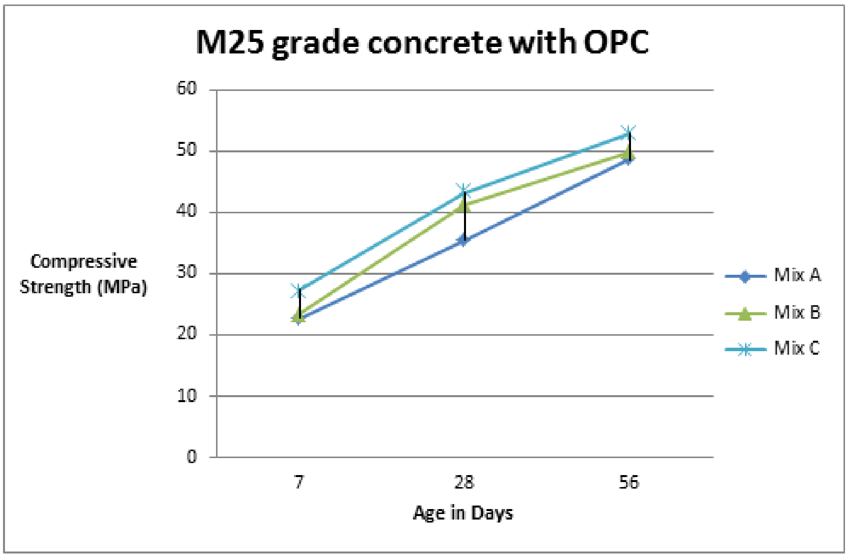

Figure 4.1: Compressive strength for M25 grade concrete with OPC

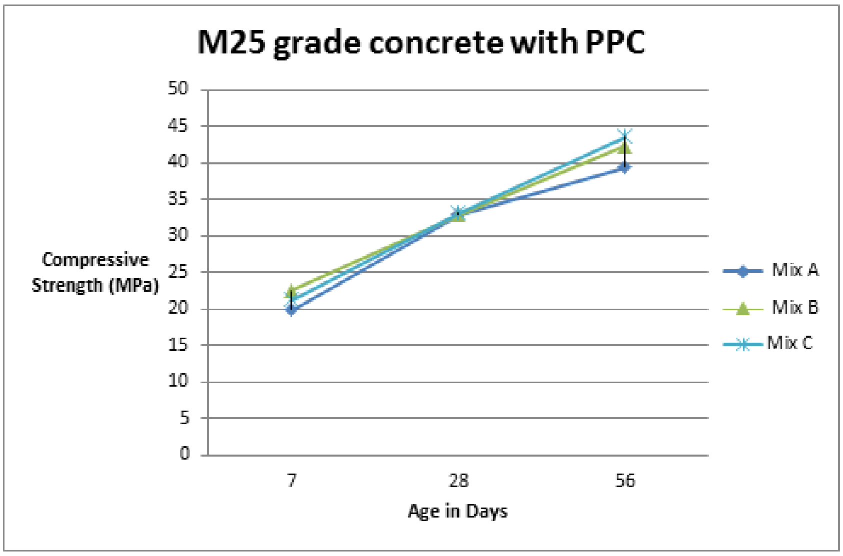

Figure 4.2: Compressive strength for M25 grade concrete with PPC

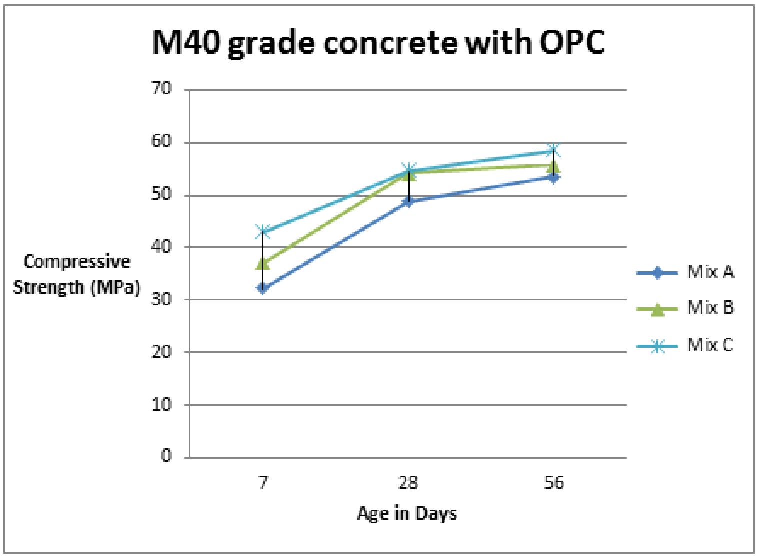

Figure 4.3: Compressive strength for M40 grade concrete with OPC

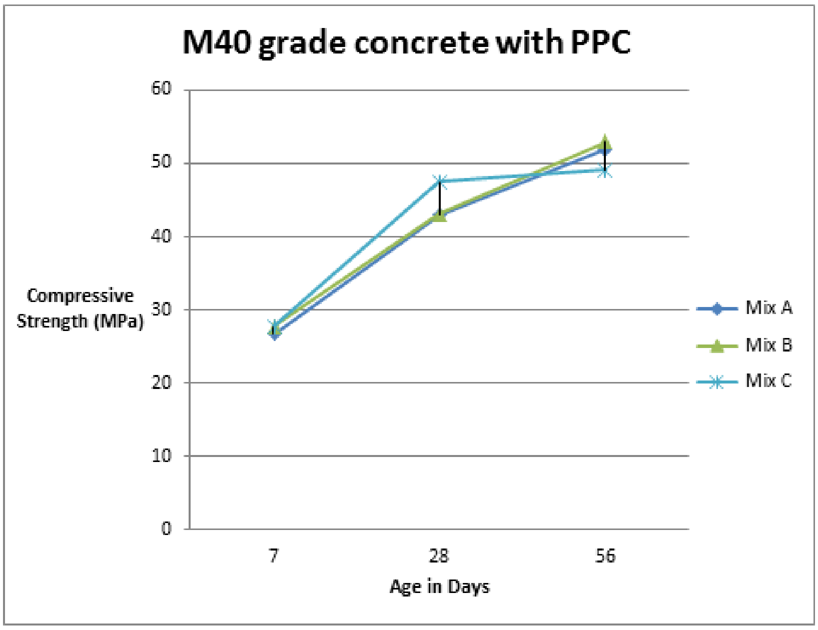

Figure 4.4: Compressive strength for M40 grade concrete with PPC

Increase in compressive strength of all concrete mixes is observed with change in age for both types of cements i.e. OPC and PPC as well as for both concrete grades i.e. M25 and M40 respectively.

Table 4.4: % change in compressive strength for M25 grade OPC based concrete

Curing age in days	Mix	7 days			28 days			56 days		
		A	B	C	A	B	C	A	B	C
7	A	0	-	-	-	-	-	-	-	-
	B	3.22	0	-	-	-	-	-	-	-
	C	20.86	17.09	0	-	-	-	-	-	-
28	A	56.15	51.28	29.19	0	-	-	-	-	-
	B	82.17	76.49	50.72	16.66	0	-	-	-	-
	C	90.82	84.87	57.88	22.20	4.74	0	-	-	-
56	A	114.3	107.64	77.33	37.25	17.65	12.32	0	-	-
	B	119.58	112.73	81.67	40.62	20.53	15.07	2.44	0	-
	C	133.3	126.02	93.02	49.40	28.06	22.26	8.84	6.24	0

Table 4.4 shows % change in compressive strength for M25 grade OPC based concrete after 7, 28 and 56 days.

Increase in compressive strength of 3.22% and 20.86% is observed for M25 grade concrete with OPC for Mix-B and Mix-C respectively as compared to Mix-A after 7 days. Increase of 16.66% and 22.20% in compressive strength is observed for M25 grade concrete with OPC for Mix-B and Mix-C respectively as compared to Mix-A after 28 days. Increase of 2.44% and 8.84% in compressive strength is observed for M25 grade concrete with OPC for Mix-B and Mix-C respectively as compared to that of Mix-A after 56 days.

Increase in compressive strength is observed for M25 grade OPC based concrete for Mix-B and Mix-C with increase in age. Compressive strength gain in M25 grade OPC based concrete for Mix-C is more up to 56 days age as compared to that of Mix-A and Mix-B.

Table 4.5: % change in compressive strength for M25 grade PPC based concrete

Mix	7 days			28 days			56 days		
	A	B	C	A	B	C	A	B	C
A	0	-	-	-	-	-	-	-	-
B	13	0	-	-	-	-	-	-	-
C	6.32	-	0	-	-	-	-	-	-
A	65.1	46.09	55.2	0	-	-	-	-	-
B	65.1	46.09	55.26	0	0	-	-	-	-
C	66.5	47.38	56.63	0.88	0.88	0	-	-	-
A	97.7	74.96	85.93	19.75	19.8	18.71	0	-	-
B	113	88.14	99.9	28.78	28.8	27.66	7.54	0	-
C	119	93.43	105.57	32.40	32.4	31.24	10.6	2.81	0

Table 4.5 shows % change in compressive strength for M25 grade PPC based concrete after 7, 28 and 56 days.

Increase in compressive strength of 13% and 6.32% is observed for M25 grade concrete with PPC for Mix-B and Mix-C respectively as compared to Mix-A after 7 days. Almost same compressive strength is observed for M25 grade concrete with PPC for Mix-B and Mix-C respectively as compared to Mix-A after 28 days. Increase of 7.54% and 10.6% in compressive strength is observed for M25 grade concrete with PPC for Mix-B and Mix-C respectively as compared to that of Mix-A after 56 days.

The results show that after 28 days all three mixes perform similar. Up to 56 days, increase in compressive strength of M25 grade PPC based concrete for Mix-C is observed as compared to that of Mix-A and Mix-B.

Table 4.6: % change in compressive strength for M40 grade OPC based concrete

Mix	7 days			28 days			56 days		
	A	B	C	A	B	C	A	B	C
A	0	-	-	-	-	-	-	-	-
B	15.4	0	-	-	-	-	-	-	-
C	33.6	15.76	0	-	-	-	-	-	-
A	51.6	31.34	13.45	0	-	-	-	-	-
B	68.2	45.7	25.86	10.93	0	-	-	-	-
C	69.6	46.91	26.90	11.85	0.83	0	-	-	-
A	66.8	44.49	24.81	10.01	-	-	0	-	-
B	73.3	50.09	29.65	14.28	3.01	2.16	3.88	0	-
C	82	57.67	36.19	20.04	8.21	7.31	9.12	5.04	0

Table 4.6 shows % change in compressive strength for M40 grade OPC based concrete after 7, 28 and 56 days.

Increase in compressive strength of 15.4% and 33.6% is observed for M40 grade concrete with OPC for Mix-B and Mix-C respectively as compared to Mix-A after 7 days. Increase of 10.9% and 11.85% in compressive strength is observed for M40 grade concrete with OPC for Mix-B and Mix-C respectively as compared to Mix-A after 28 days. Increase of 4% and 9.1% in compressive strength is observed for M40 grade concrete with OPC for Mix-B and Mix-C respectively as compared to that of Mix-A after 56 days.

The results show that increase in compressive strength for M40 grade OPC based concrete for Mix-C is observed than Mix-A and Mix-B.

Table 4.7: % change in compressive strength for M40 grade PPC based concrete

Mix	7 days			28 days			56 days		
	A	B	C	A	B	C	A	B	C
A	0	-	-	-	-	-	-	-	-
B	-	0	-	-	-	-	-	-	-
C	-	0	0	-	-	-	-	-	-
A	53.4	55.09	55.09	0	-	-	-	-	-
B	54	55.63	55.63	0.34	0	-	-	-	-
C	69.3	71.12	71.11	10.33	9.95	0	-	-	1.26
A	85.2	87.18	87.18	20.69	20.3	9.38	0	-	10.77
B	88.9	90.94	90.93	23.11	22.7	11.58	2.01	0	12.99
C	67.2	68.99	68.98	8.96	8.58	-1.24	-9.7	-11.5	0

Table 4.7 shows % change in compressive strength for M40 grade PPC based concrete after 7, 28 and 56 days.

Almost similar compressive strength is observed for M40 grade concrete with PPC for Mix-B and Mix-C respectively as compared to Mix-A after 7 days. Increase of 0.34% and 10.33% in compressive strength is observed for M40 grade concrete with PPC for Mix-B and Mix-C respectively as compared to Mix-A after 28 days. Almost similar compressive strength is observed for M40 grade concrete with PPC for Mix-B as compared to Mix-A after 56 days. Due to poor workmanship or any other reason Mix-C shows 9% less results as compared to that of Mix-A.

The increment observed in compressive strength of concrete using DMS is due to the higher chloride content in DMS as compared to natural river sand. The chloride content present in DMS accelerates the compressive strength during 28 days curing.

4.3 Durability properties of concrete mixes

4.3.1 Acid exposure

The plain concrete specimens are exposed in the tank with acid solution for designated age in terms of months. After completion of the exposure, the concrete specimens are taken out of the tank. The pH value of the acid solution is measured which is maintained having value between 0.80 and 0.87.

The specimens are taken out of the tank after 3 months of exposure. The evaluation of change in mass and change in compressive strength is conducted for all concrete mixes. The results of change in compressive strength are presented in Table 4.8. Graphical representation of results is shown in Fig 4.5. The results of change in mass of the concrete specimens are shown in Table 4.9. The graphical representation related to the same is shown in Fig 4.6.

Table 4.8: Acid resistance test for concrete mixes

Grade of concrete	Cement type	Mix	Compressive strength after 28 days curing (MPa)	Compressive strength after 3 months exposure (MPa)	Reduction in compressive strength (%)
M25	OPC	Mix A	35.4	25.33	39.75
		Mix B	41.3	34.67	19.12
		Mix C	43.26	38.96	11.03
M25	PPC	Mix A	32.9	26.44	24.43
		Mix B	32.9	29.33	12.17
		Mix C	33.19	29.48	12.58
M40	OPC	Mix A	48.74	36.22	34.56
		Mix B	54.07	45.33	19.28
		Mix C	54.52	46.52	17.19
M40	PPC	Mix A	42.96	38.22	12.40
		Mix B	43.11	40.15	7.372
		Mix C	47.4	42.82	10.69

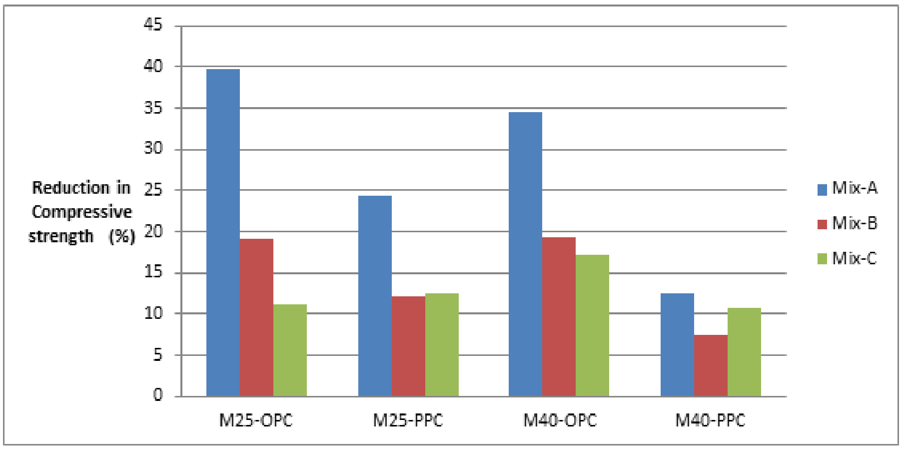

Figure 4.5: % change in compressive strength of concrete mixes for acid exposure of 3 months

The results indicate that the compressive strength of M25 grade concrete with OPC for Mix-C has less percentage reduction as compared to that for Mix-A and Mix-B, respectively. 40% reduction in compressive strength is observed for concrete Mix-A. On the other hand 19% and 12% reduction in compressive strength is observed in Mix-B and Mix-C, respectively. 24% reduction in compressive strength is observed for concrete Mix-A, whereas 12% reduction in compressive strength is observed for Mix-B and Mix-C, respectively for M25 grade PPC based concrete.

For M40 grade concrete with OPC for Mix-A indicate higher percentage of reduction in compressive strength of 35%. 15% of strength reduction in compressive strength is observed in concrete Mix-B and Mix-C after 3 months of exposure in acid solution. The concrete made with PPC of M40 grade show 13% reduction in compressive strength for concrete Mix-A. In case of Mix-C and Mix-B, 10% and 7% reduction in compressive strength is observed respectively.

The compressive strength of concrete specimens for all mixes after 28 days is compared with corresponding compressive strength for the mixes after completion of 3 months acid exposure.

Table 4.9: Change in weight of concrete mixes for acid resistance test

Grade of concrete	Cement type	Mix	Initial weight (kg)	Final Weight (kg)	Reduction in weight (%)
M25	OPC	Mix A	8.56	8.17	4.70
		Mix B	8.72	8.39	4.01
		Mix C	8.87	8.55	3.74
M25	PPC	Mix A	8.53	8.16	4.57
		Mix B	8.75	8.43	3.79
		Mix C	8.80	8.50	3.48
M40	OPC	Mix A	8.52	8.16	4.40
		Mix B	8.82	8.49	3.96
		Mix C	8.88	8.55	3.89
M40	PPC	Mix A	8.74	8.39	4.08
		Mix B	8.69	8.37	3.82
		Mix C	8.94	8.62	3.71

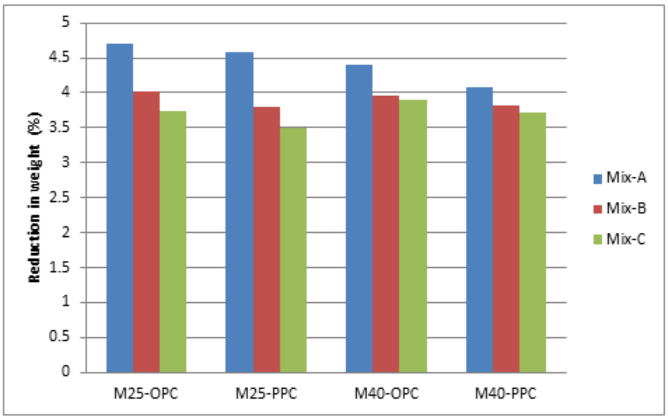

Figure 4.6: Reduction in weight of concrete specimens after acid exposure of 3 months

The results of reduction in weight after completion of acid exposure of 3 months duration are shown in Fig 4.6. The results show that the percentage reduction in concrete Mix-C and Mix-B is less as compared to that of Mix-A.

The test results for acid exposure show that concrete Mix-C is superior against acid attack as compared to Mix-A and Mix-B, respectively.

4.3.2 Sulfate exposure

The plain concrete specimens are exposed in the tank with sulfate solution for designated age in terms of months. After completion of the exposure, the concrete specimens are taken out of the tank. The pH value of the sulfate solution is measured which is maintained having value between 8 and 9.

The specimens are taken out of the tank after 3 months of exposure. The evaluation of change in mass and change in compressive strength is conducted for all concrete mixes. The results of change in compressive strength are presented in Table 4.10. Graphical representation of results is shown in Fig 4.7. The results of change in mass of concrete specimens are shown in Table 4.11. The graphical representation related to the same is shown in Fig 4.8. For exploring the quality of specimens UPV test was performed for all specimens before and after completion of exposure of 3 months. The results are presented in Table 4.12.

Table 4.10: Sulfate resistance test for concrete mixes

Grade of concrete	Cement type	Mix	Compressive strength after 28 days curing (MPa)	Compressive strength after 3 months exposure (MPa)	Reduction in compressive strength (%)
M25	OPC	Mix A	35.4	34.22	3.44
		Mix B	41.3	40.3	2.48
		Mix C	43.26	42.22	2.46
M25	PPC	Mix A	32.9	31.25	5.28
		Mix B	32.9	31.8	3.45
		Mix C	33.19	32.89	0.91
M40	OPC	Mix A	48.74	46.22	5.45
		Mix B	54.07	53	2.01
		Mix C	54.52	53.48	1.94
M40	PPC	Mix A	42.96	40.74	5.44
		Mix B	43.11	42.22	2.10
		Mix C	47.4	47.26	0.29

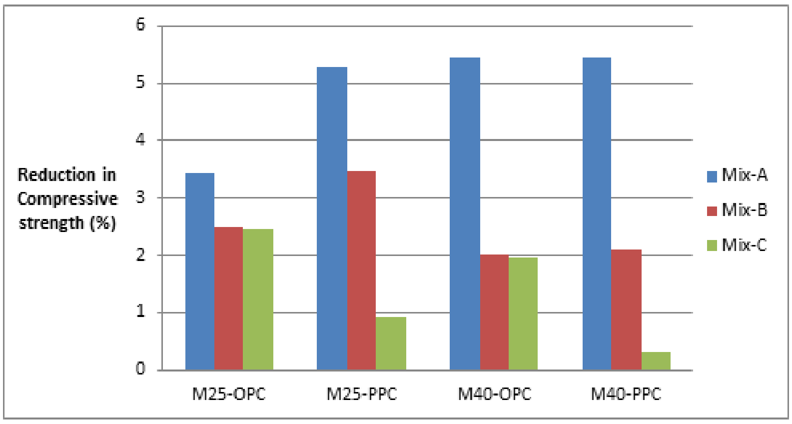

Figure 4.7: % change in compressive strength of concrete mixes for sulfate exposure of 3 months

The reduction in compressive strength in percentage is from 1% to 5% for all concrete mixes. For M25 grade of concrete with OPC show almost same values of compressive strength reduction for all three concrete mixes. In case of M25 grade concrete with PPC, % reduction in compressive strength is less in Mix-C as compared to that of Mix-B and Mix-A.

For M40 grade concrete made with OPC and PPC both for Mix-A and Mix-B show more reduction in strength as compared to Mix-C.

The compressive strength of concrete specimens for all mixes after 28 days is compared with corresponding compressive strength for the mixes after completion of 3 months sulfate exposure.

Table 4.11: Change in weight of all concrete mixes for sulfate resistance test

Grade of concrete	Cement type	Mix	Initial weight (kg)	Final Weight (kg)	Increase in weight (%)
M25	OPC	Mix A	8.53	8.67	1.60
		Mix B	8.51	8.54	0.27
		Mix C	8.77	8.79	0.22
M25	PPC	Mix A	8.43	8.54	1.33
		Mix B	8.74	8.77	0.34
		Mix C	8.76	8.77	0.11
M40	OPC	Mix A	8.50	8.54	0.50
		Mix B	8.81	8.83	0.17
		Mix C	8.59	8.62	0.34
M40	PPC	Mix A	8.53	8.67	1.64
		Mix B	8.75	8.77	0.26
		Mix C	8.85	8.87	0.22

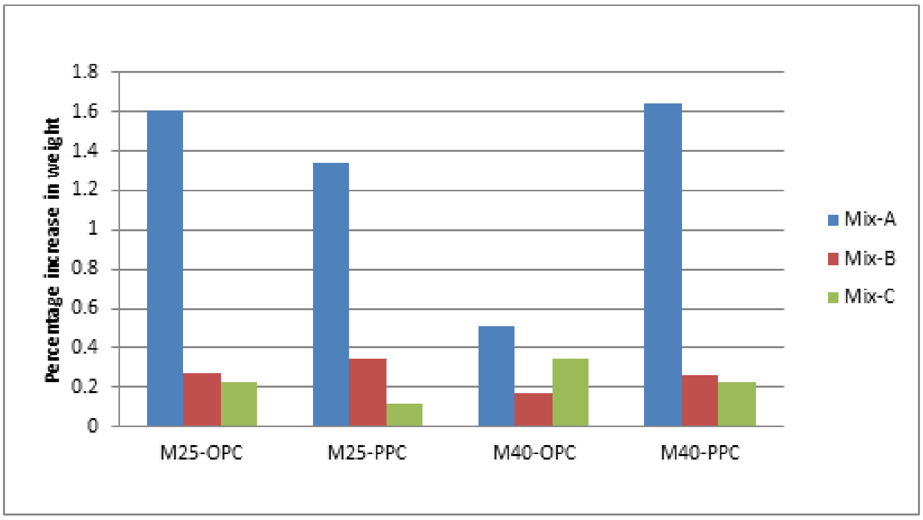

Figure 4.8: Increase in weight of specimens after 3 months of sulfate exposure

The chemical consequences of sulfate attack on concrete components are the formation of ettringite (calcium aluminate trisulfate 32 hydrate, $CaOAl_2O_33CaSO_432H_2O$) and gypsum (calcium sulfate dihydrate, $CaSO_42H_2O$). The formation of ettringite can result in an increase in solid volume, leading to expansion and cracking. The formation of gypsum can lead to softening and loss of concrete strength.[16] Both increase in weight and loss in compressive strength of concrete are observed from previous results shown in Table 4.10 and 4.11, respectively.

Table 4.12: Average UPV results for sulfate exposure for all concrete mixes

Grade of concrete	Cement type	Mix	Initial reading (m/s)	Final reading (m/s)
M25	OPC	Mix A	4770	4746
		Mix B	4663	4646
		Mix C	4860	4843
M25	PPC	Mix A	4666	4646
		Mix B	4783	4766
		Mix C	4776	4760
M40	OPC	Mix A	4793	4776
		Mix B	4810	4793
		Mix C	4990	4973
M40	PPC	Mix A	4863	4846
		Mix B	4730	4713
		Mix C	4843	4826

The test results for sulfate exposure show that Mix-C performs better as compared to that of Mix-B and Mix-A.

4.3.3 Chloride exposure

The plain concrete specimens are exposed in the tank with chloride solution for designated age in terms of months. After completion of the exposure, the concrete specimens are taken out of the tank. The pH value of the chloride solution is measured which is maintained having value between 9 and 9.8.

The specimens are taken out of the tank after 2 months of exposure. The evaluation of change in mass and change in compressive strength is conducted for all concrete mixes. The results of change in compressive strength are presented in Table 4.13. Graphical representation of results is presented in Fig 4.9. The results of change in mass of the concrete specimens are shown in Table 4.14. The graphical representation related to the same is shown in Fig 4.10. For exploring the quality of specimens UPV test was performed for all specimens before and after exposure. The results are shown in Table 4.15.

Table 4.13: Chloride resistance test for concrete mixes

Grade of concrete	Cement type	Mix	Compressive strength after 28 days curing (MPa)	Compressive strength after 3 months exposure (MPa)	Reduction in compressive strength (%)
M25	OPC	Mix A	35.4	35.11	0.82
		Mix B	41.3	38.81	6.41
		Mix C	43.26	38.455	12.49
M25	PPC	Mix A	32.9	32.89	0.03
		Mix B	32.9	31.26	5.24
		Mix C	33.19	29	14.44
M40	OPC	Mix A	48.74	48.29	0.93
		Mix B	54.07	48	12.64
		Mix C	54.52	42.6	27.98
M40	PPC	Mix A	42.96	42.37	1.39
		Mix B	43.11	41.19	4.66
		Mix C	47.4	38.9	21.85

Fig 4.9 shows that the results for the compressive strength of concrete specimens of

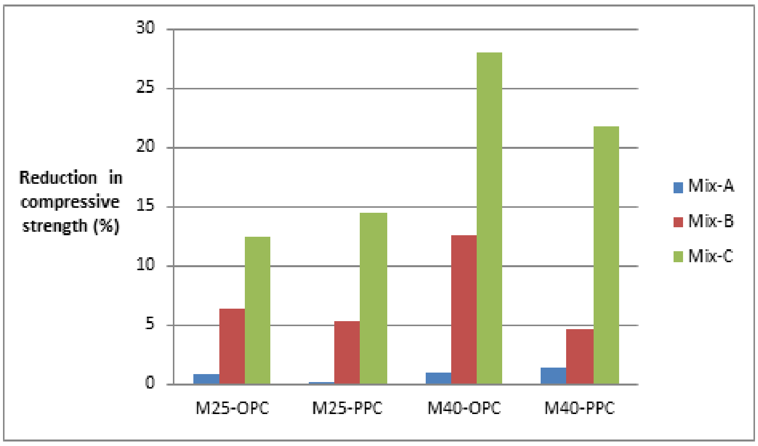

Figure 4.9: % change in compressive strength of concrete mixes for chloride exposure of 2 months

M25 grade with OPC for Mix- C shows more reduction in strength of 13% as compared to Mix-A. For PPC Mix-C, the results show 12% of reduction in compressive strength which is more as compared to Mix-B and Mix-A. For PPC, the reduction in compressive strength is 14% in case of Mix-C which is more as compared to Mix-A.

For M40 grade concrete made with OPC and PPC both for Mix-C show more reduction in compressive strength as compared to Mix-A. The percentage reduction in compressive strength is 21.85% for Mix-C with OPC and 28% for Mix-C with PPC respectively. The percentage reduction in compressive strength is 12.64% for Mix-B with OPC and 4.66% for Mix-B with PPC respectively.

The compressive strength of concrete specimens for all mixes after 28 days is compared with corresponding compressive strength for the mixes after completion of 2 months chloride exposure.

The results of compressive strength of concrete specimens made with DMS indicate that the concrete have less resistance against the chloride attack for the exposure age of 2 months. Therefore further investigation is required to be made with respect to chloride resistance test for concrete made with DMS.

Table 4.14: Change in weight of all concrete mixes for chloride resistance test

Grade of concrete	Cement type	Mix	Initial weight (kg)	Final Weight (kg)	Increase in weight (%)
M25	OPC	Mix A	8.67	8.78	1.22
		Mix B	8.64	8.69	0.54
		Mix C	8.63	8.67	0.50
M25	PPC	Mix A	8.48	8.59	1.29
		Mix B	8.71	8.81	1.14
		Mix C	8.76	8.82	0.68
M40	OPC	Mix A	8.66	8.73	0.42
		Mix B	8.74	8.79	0.49
		Mix C	8.73	8.80	0.80
M40	PPC	Mix A	8.46	8.61	1.76
		Mix B	8.55	8.60	0.58
		Mix C	8.83	8.88	0.60

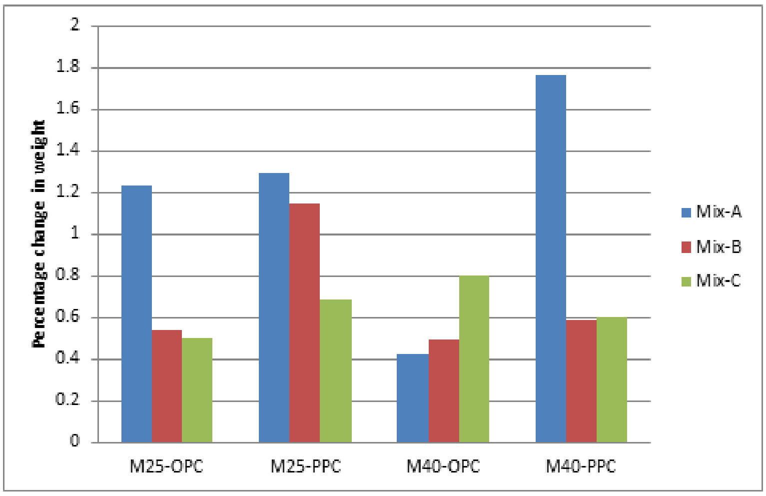

Figure 4.10: Increase in weight of specimens after 2 months of exposure in NaCl solution

Where concrete structures are placed on reclaimed coastal areas with foundations below saline groundwater level, capillary suction and evaporation may cause super-saturation and crystallization in the concrete above ground. This can result in chemical sulfate attack, physical salt attack, or both. In addition, aggravated corrosion of embedded steel can be induced by the chloride in seawater.[16] This phenomena may be applied in chloride attack, which would increase the weight of concrete after completion of exposure duration.

The results of the UPV test for all concrete mixes show that pulse velocity is not decreased with higher percentage after completion of 2 months chloride exposure.

Table 4.15: UPV results for chloride exposure for all concrete mixes

Grade of concrete	Cement type	Mix	Initial reading (m/s)	Final reading (m/s)
M25	OPC	Mix A	4723.3	4680
		Mix B	4856.7	4830
		Mix C	4860	4840
M25	PPC	Mix A	4640	4600
		Mix B	5180	5143.3
		Mix C	4950	4920
M40	OPC	Mix A	4866.7	4813.3
		Mix B	4810	4770
		Mix C	4926.7	4903.3
M40	PPC	Mix A	4646.7	4586.7
		Mix B	4956.7	4916.7
		Mix C	4843.3	4826.7

4.3.4 Accelerated corrosion test

This test explains about the corrosion rate in the embedded bars in the cylindrical concrete specimens. DC power supply is applied to the set of cylinders connected in parallel connection with each other in tank having sodium chloride concentration of 5% as shown in Fig 4.11. Fig 4.11 shows the RC specimens immersed in tank without initiation of corrosion in the reinforcement i.e. before starting of the test. Fig 4.12 indicates the RC specimens immersed in tank after initiation of corrosion in the reinforcement.

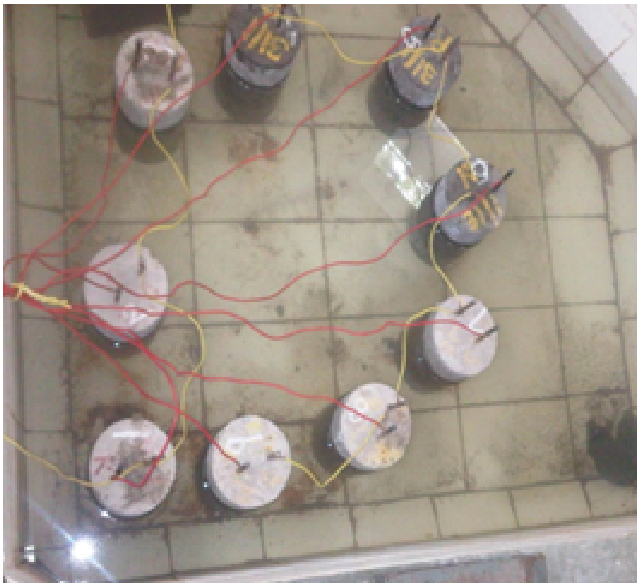

Figure 4.11: RC specimens before initiation of corrosion in the reinforcement

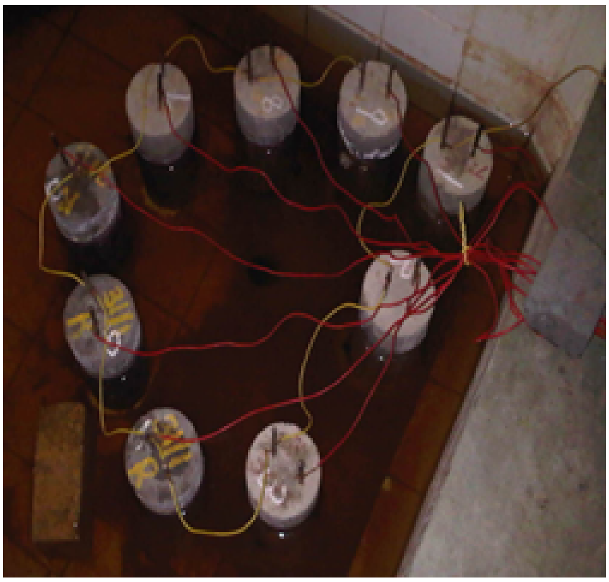

Figure 4.12: RC specimens after initiation of corrosion in the reinforcement

It is observed that within 10-15 hours of starting the power supply, the initiation of corrosion starts in the reinforcement bars for the concrete cylinder. Water with NaCl in tank also starts exhibiting the change in color due to rust formation.

Current readings for the RC specimens are taken on regular basis and variation in current is observed throughout the test. The graphical representation of the current readings for all specimens of Mix-A, Mix-B and Mix-C is shown in Fig 4.13, 4.14 and 4.15, respectively.

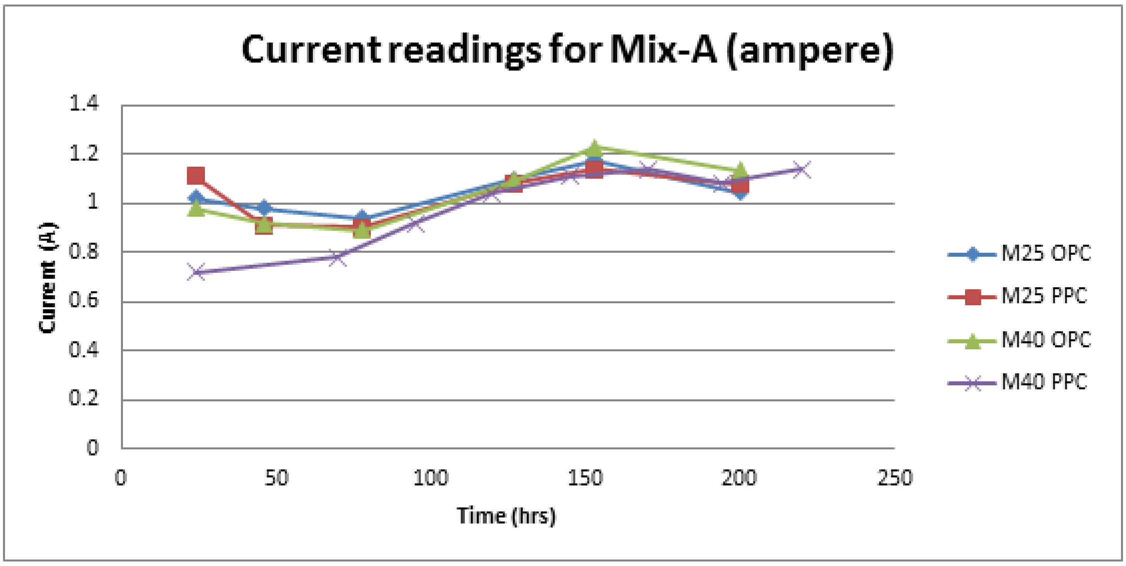

Figure 4.13: Current measurement of concrete Mix-A

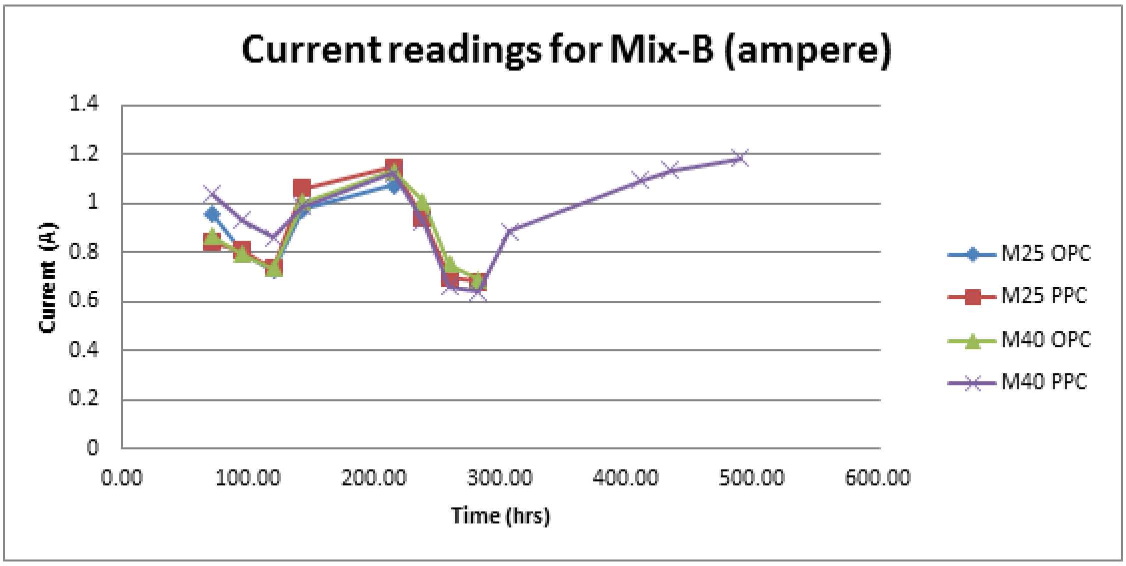

Figure 4.14: Current measurement of concrete Mix-B

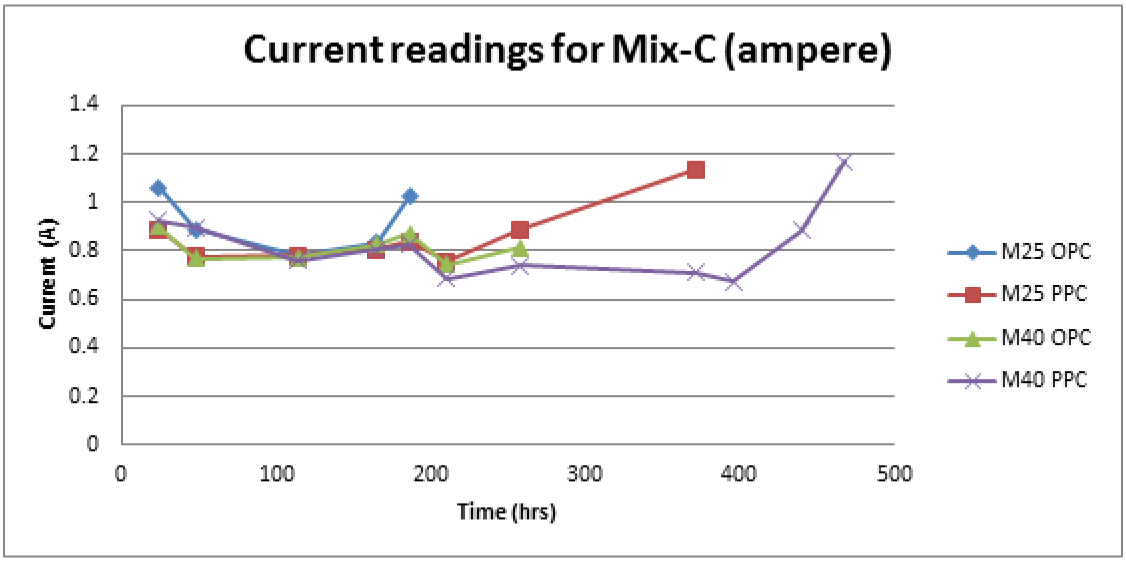

Figure 4.15: Current measurement of concrete Mix-C

The results of current measured for the ACT for all mixes indicate that at the beginning of the test the current goes down after that again it starts increasing. When the volume of the reinforcement starts increasing and cracks are initiated, the current starts increasing again and indicate further widening of cracks into the concrete specimen on the side where HYSD bar in embedded. Fig 4.16 shows the specimens after developing the cracks and corrosion of RC specimens.


Figure 4.16: RC specimens after cracks and corrosion started

Half-cell potentiometer test is also performed to check and measure the rate of corrosion in the embedded reinforcements for all concrete mixes. Fig 4.17, 4.18 and 4.19 show the results of Half-cell potentiometer test on specimens before and after the ACT for Mix-A, Mix-B and Mix-C, respectively.

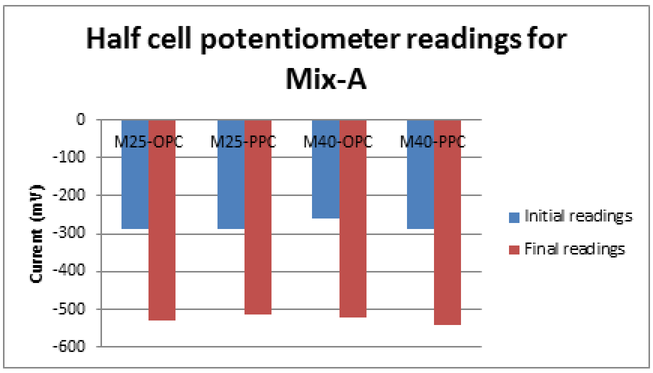

Figure 4.17: Results of half-cell potentiometer for concrete Mix-A

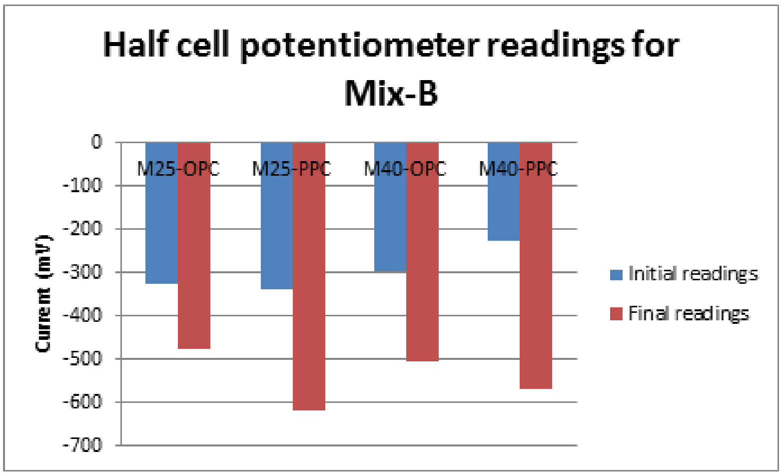

Figure 4.18: Results of half-cell potentiometer for concrete Mix-B

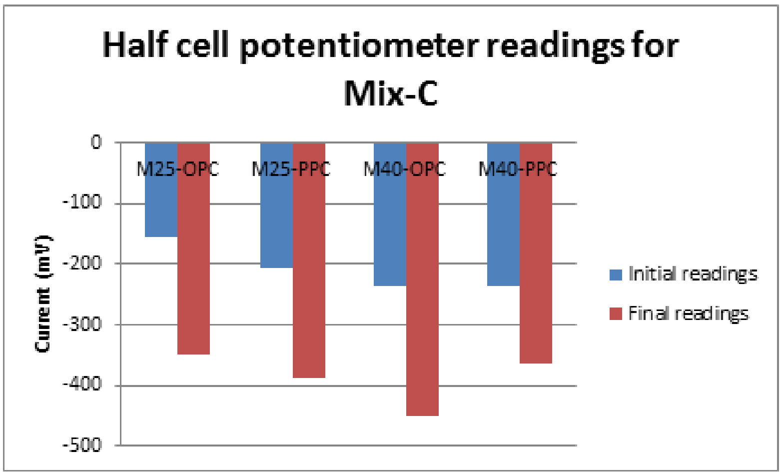

Figure 4.19: Results of half-cell potentiometer for concrete Mix-C

Readings of the half-cell potentiometer are negative and in mV unit. The higher the reading on negative side, the possibility of corrosion in the embedded bars is more. The reading more negative -350 mV indicated more possibility of active corrosion in the embedded bars.[26]

The results of half-cell potentiometer test show that values for the RC specimens before starting the test, are not beyond negative -350 mV which indicate less possibility of corrosion in reinforcement bar in concrete specimen. After completion of test due to development of crack in specimen the reading of half-cell potentiometer less than negative -350 mV. For concrete Mix-C and Mix-B, it is observed that the percentage difference of half-cell potential reading is less as compared to that of Mix-A. This shows that the concrete Mix-C and Mix-B have more resistance against the corrosion as compared to that of Mix-A.

The time taken for initiating the cracks in the RC specimens is to be measured. Fig 4.20, 4.21 and 4.22 show the time period required for initiation of cracks in the specimens for Mix-A, Mix-B and Mix-C respectively.

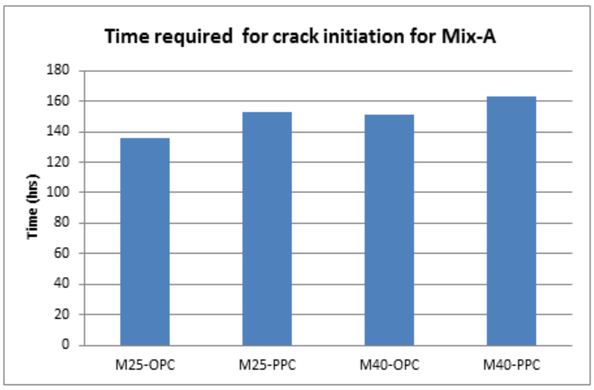

Figure 4.20: Time required for crack initiation for Mix-A

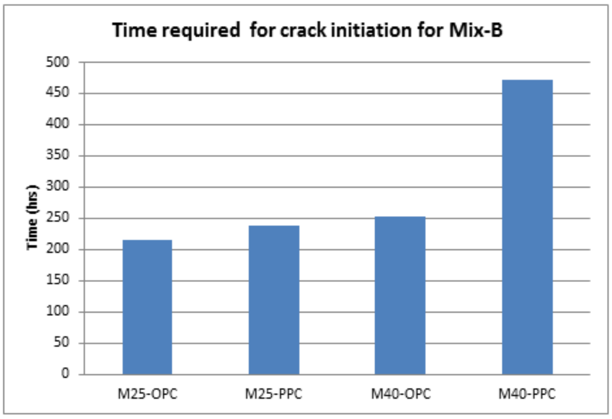

Figure 4.21: Time required for crack initiation for Mix-B

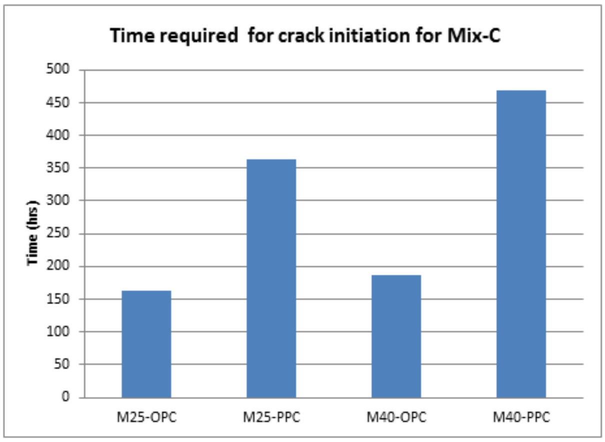

Figure 4.22: Time required for crack initiation for Mix-C

The results have clearly demonstrated that concrete Mix-C consumes more time for crack development as compared to that of concrete Mix-B and Mix-A, respectively for all concrete mixes.

UPV test is done on all the cylinders before commencing of the test and after completion of test. Fig 4.23 and 4.24 indicate the results of UPV test on RC specimens for ACT for concrete of both grades.

Results of UPV test shows that quality of the specimens after completion of test is decreased as expected and as cracks are developing in the concrete due to increase in volume of embedded bar within the specimens. Higher percentage decrease is found in case of Mix-A as compared to Mix-B and Mix-C. The percentage reduction in velocity is found nearly 18% to 23% in Mix-A.

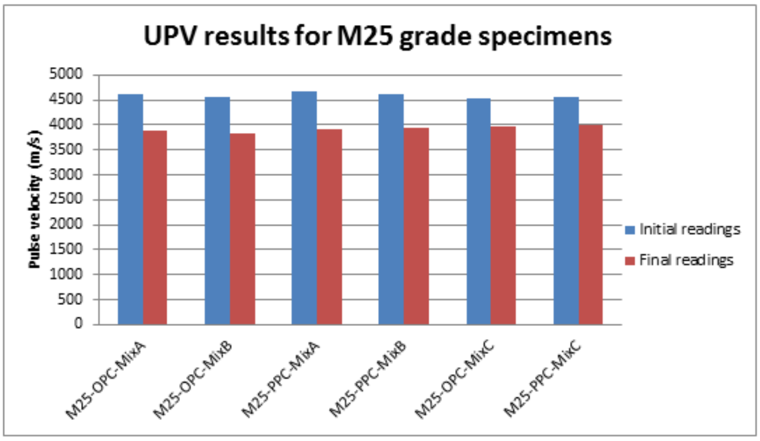

Figure 4.23: UPV results for M25 grade RC specimens

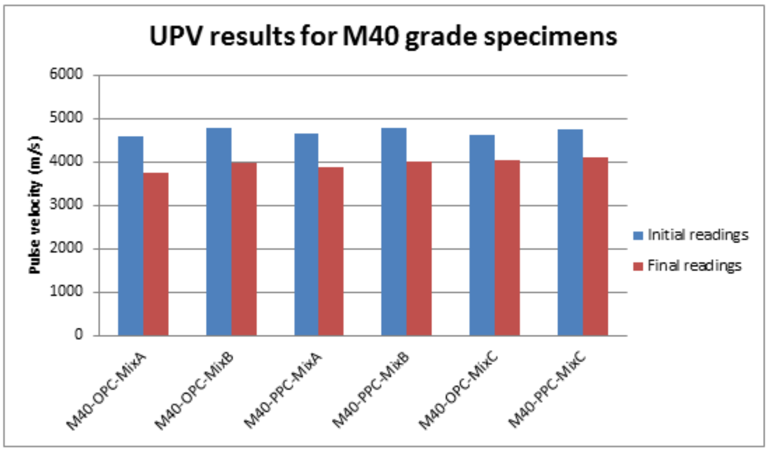

Figure 4.24: UPV results for M40 grade RC specimens

4.3.5 Sorptivity test

This test is performed to know the capillary action of water or any other liquid when plain concrete comes in contact with it. The results of this test are determined in mm/min0.5 unit is called sorptivity (S). The sorptivity test results of all concrete mixes are presented in Table 4.16.

Table 4.16: Sorptivity test for concrete mixes

Concrete mix	Grade of concrete	Cement type	Sorptivity (S) ($mm/min^{0.5}$)
Mix-A	M25	OPC	0.086
	M25	PPC	0.108
	M40	OPC	0.076
	M40	PPC	0.087
Mix-B	M25	OPC	0.072
	M25	PPC	0.091
	M40	OPC	0.074
	M40	PPC	0.082
Mix-C	M25	OPC	0.068
	M25	PPC	0.078
	M40	OPC	0.074
	M40	PPC	0.080

Figs 4.25, 4.26 and Fig 4.27 show graphical representation of sorptivity test results for concrete mixes Mix-A, Mix-B and Mix-C, respectively. The orange line in graphs shows actual behavior and black line indicates best fit curve i.e. linear graph for corresponding concrete mixes, respectively.

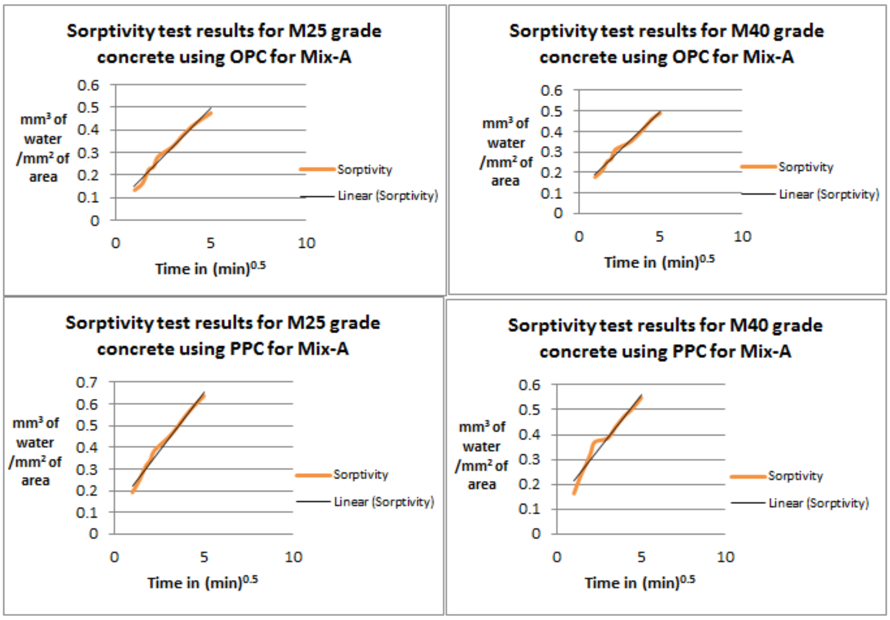

Figure 4.25: Sorptivity test result for Mix-A

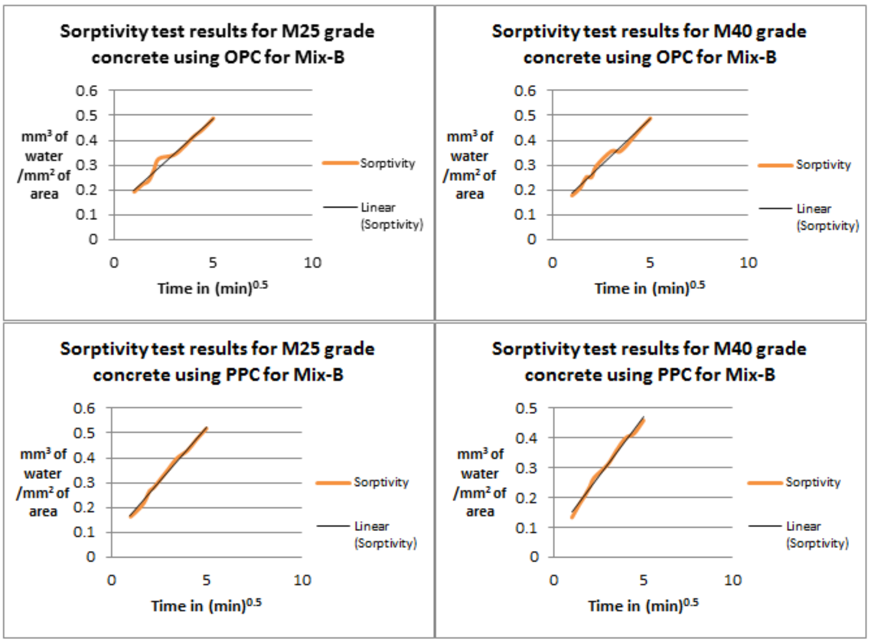

Figure 4.26: Sorptivity test result for Mix-B

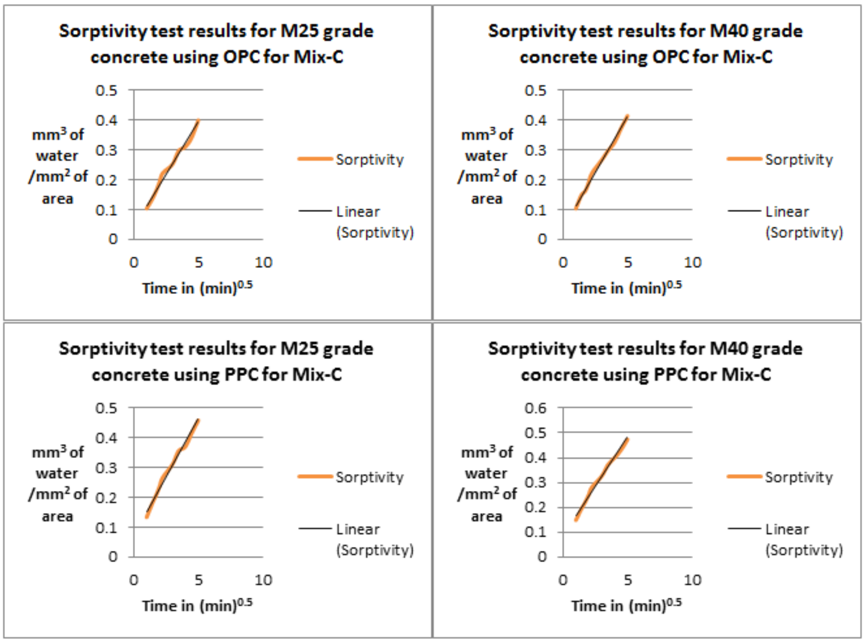

Figure 4.27: Sorptivity test result for Mix-C

After studying the behavior of all mixes related with sorptivity of the concrete, concrete made with 100% dredged marine sand i.e. Mix-C shows better results as compared to other two mixes i.e. Mix-A and Mix-B, respectively. Concrete Mix-C shows less water absorption due to capillary action as compared to that of Mix-A and Mix-B. This is due to the fine particles available in DMS and which makes the concrete less porous as compared to the control concrete.

4.3.6 Water absorption test

The test is performed first by putting concrete specimens of all concrete mixes in oven @ 105 C for complete drying for 24 hours. Then after they are taken out and weighed which will be taken as initial weight (w_1) and then immersed in clean water again for 24 hours. All the specimens are taken out of the tank and allow them to dry in atmosphere for some duration until they reach to the saturated surface dry

(SSD) condition. Then all the specimens are weighed which would be considered as final weight (w_2) of the specimens. Table 4.17 shows the average gain in mass of the specimens for all concrete mixes.

Table 4.17: Water absorption test results for all concrete mixes

Concrete mix	Grade of concrete	Cement type	Initial wt. w_1 (kg)	Final wt. w_2 (kg)	Water absorption (%)
Mix-A	M25	OPC	8.607	8.725	1.67
	M25	PPC	8.305	8.469	1.97
	M40	OPC	8.685	8.794	1.25
	M40	PPC	8.514	8.624	1.29
Mix-B	M25	OPC	8.537	8.673	1.6
	M25	PPC	8.502	8.624	1.41
	M40	OPC	8.650	8.720	0.81
	M40	PPC	8.627	8.716	1.02
Mix-C	M25	OPC	8.509	8.627	1.24
	M25	PPC	8.345	8.486	1.35
	M40	OPC	8.649	8.730	0.72
	M40	PPC	8.515	8.599	0.98

Fig 4.28 shows the graphical representation of water absorption test of all concrete mixes. The results indicate that concrete Mix-C shows less water absorption as compared to that of Mix-A and Mix-B, respectively for both concrete grade M25 and M40 made using OPC and PPC both.

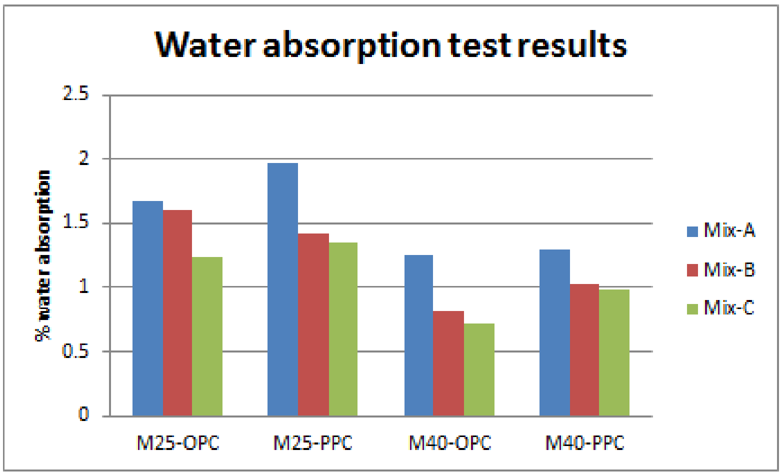

Figure 4.28: Water absorption test results for all concrete mixes

The concrete made with DMS showing slightly less percentage of water absorption as compared to that with river sand because of the presence of finer particles in DMS, which makes concrete less permeable which reduces the porosity of the concrete.

Chapter 5

Concluding remarks and future scope of work

5.1 Summary

The experiment is based on three types of concrete mixes i.e. Mix-A which is made with 100% natural river sand, Mix-B which is made with 50% replacement of natural river sand with dredged marine sand and Mix-C which is made with 100% replacement of natural river sand with dredged marine sand. Two different concrete grades are considered i.e. M25 and M40. Two cement types are taken into account i.e. OPC and PPC.

Basic information related to dredged marine sand i.e. the equipment used for dredging the marine sand, specification of the dredger, practical applications, location of site from where marine sand has been extracted etc. was done. The aggregates used as a fine aggregate are river sand which is locally available and raw dredged marine sand. The coarse aggregates which are used in concrete manufacturing are of size 10 mm and 20 mm, respectively. Sieve analysis and specific gravity tests are performed for the aggregates. Concrete mix design is done for two concrete grades such as M25 and M40. Casting of plain concrete specimens and RC specimens is done.

Mechanical properties such as compressive strength of plain concrete specimens are measured after 7, 28 and 56 days of moist curing for all mixes. The durability properties i.e. acid resistance, sulfate resistance after exposure of 3 months, chloride resistance after exposure of 2 months, water absorption test, sorptivity test and accelerated corrosion test is performed for all concrete mixes. For acid exposure and sulfate exposure 5% H_2SO_4 and 5% Na_2SO_4 is used, respectively. For chloride exposure 3% NaCl is used during the test. The time required for initiation of cracks in concrete specimens is measured. Corrosion rate using half-cell potentiometer is measured and current measurement for individual specimens during the test is determined. UPV test is conducted for concrete specimens after various durability tests.

5.2 Concluding remarks

Following remarks are made after conducting experimental work in major project.

Mechanical properties:

- Increase in compressive strength of all concrete mixes is observed with change in age for both types of cements i.e. OPC and PPC as well as for both concrete grades i.e. M25 and M40 respectively.
- Compressive strength gain in M25 grade OPC based concrete for concrete Mix-C is more up to 56 days age as compared to that of concrete Mix-A and Mix-B.
- Up to 56 days, increase in compressive strength of M25 grade PPC based concrete for concrete Mix-C is observed as compared to that of concrete Mix-A and Mix-B..

- For M40 grade concrete made using OPC, compressive strength is higher for Mix-C and Mix-B as compared to that of concrete Mix-A.

- Increase in compressive strength is slightly higher for M40 grade PPC based concrete for Mix-B as compared to that for concrete Mix-C and Mix-A, respectively.

- No major change is observed in compressive strength of concrete for M25 and M40 grade OPC based concrete for Mix-B and Mix-C from 28 days to 56 days.

- The increment observed in compressive strength of concrete using DMS is due to the higher chloride content in DMS as compared to natural river sand. The chloride content present in DMS accelerates the compressive strength during 28 days curing.

Durability properties:

- Reduction in compressive strength and weight after completion of acid and sulfate exposure for Mix-B and Mix-C are less as compared to that of concrete Mix-A for 3 months of exposure, which indicates that concrete made using DMS performed satisfactorily as compared to that with natural river sand.

- Reduction in compressive strength is observed higher in case of concrete Mix-B and Mix-C as compared to that of concrete Mix-A for chloride exposure of 2 months, which indicates that concrete made with DMS has less resistance against chlorides. Further investigations are required to be made for the chloride resistance of concrete with DMS.

- Corrosion rate determination using half-cell potentiometer is observed in embedded reinforcement for concrete Mix-C and Mix-B, which is less as compared to that of Mix-A after completion of accelerated corrosion test.

- Time required for crack initiation in specimens of Mix-A is less as compared to specimens of Mix-B and Mix-C which indicate better resistance against corrosion for concrete made using dredged marine sand.

- The sorptivity for the specimens of Mix-C found less as compared to concrete Mix-B and Mix-A.

- Water absorption is found less in case of concrete specimens of Mix-C as compared to concrete Mix-B and Mix-A.

- For the tests and duration attempted in present investigation, it allows the successful use of dredged marine sand in concrete construction activities.

5.3 Future scope of work

The study may be further extended to include following aspects in the work:

- Replacement of river sand with dredged marine sand with various different percentages other than 50% and 100% tried in the present study.

- Investigation of other mechanical properties i.e. split tensile strength and flexural strength for concrete mixes using dredged marine sand.

- The behavior of RC beam, column and beam-column joint may be investigated using concrete with dredged marine sand.

- Other durability tests such as permeability test, chloride ion penetration test etc. may be included.

- The durability tests may be extended to RC elements cast using dredged marine sand.

- Concrete made with dredged marine sand as fine aggregate and by using fly ash, silica fume, rice husk ash, slag etc. in addition to OPC.

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