CONCRETE IN THE MARINE ENVIRONMENT

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Concrete in the Marine Environment

By

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A project dissertation submitted to the
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December 2009

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

(SAMIH YASLAM MOHAMED ELSADIG)

The 21st century is known as the century of concrete in the oceans. The reasons for this prediction are:

1. Human population is expected to grow more and more.
2. The need to improve the living conditions around the world.

The search for solutions to improve the standard of living has already provided a major imputes for the exploitation of coastal and undersea energy and mineral resources.

The project is studying the effects of seawater in the marine environment on the concrete. The project focuses mainly on the changing properties of concrete mainly the porosity of concrete and the effects of seawater on it compared with the age of concrete.

Three experiments are carried out on 2 groups of concrete cubes (50mmx50mm) and (150mmx150mm) dimensions. Samples of the cured concrete cubes (50mmx50mm) after calculating their porosity through a porosity test are submerged under seawater for periods varies from 2 to 6 weeks to 10 weeks. Calculations are made on those samples to measure the chloride diffusion after being exposed to seawater. A compressive strength test is made on (150mmx150mm) concrete cubes to measure the compressive strength.

The data obtained from the experiments are collected and compared to those data obtained from a site visit was planned to Bashair Marine Terminal in Portsudan, Sudan to decide on which concrete mix is the most optimum mix.

First and foremost, the author would like to express his most gratitude to Allah S.W.T for all His blessings for making the entire things possible while his conducting this final year project.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Many industrial materials commonly used for structural purposes, do not show long term durability in the marine environment, however Portland cement concrete has proved to be an exception and therefore, it is increasingly used for the construction of concrete structures . Many oil and gas production platforms consisting of heavily reinforced and prestressed concrete elements have been built. Many sophisticated structures such as, super span cantilever concrete bridges, undersea concrete tunnels, storm barriers, and man mad concrete islands such as, palms island in Dubai are either constructed or under planning and construction. Such structures would be needed for ocean transport, exploitation of subsea hydrocarbons and wave energy, sea food production as well as for marine infrastructure.

Marine environment is contaminated with chloride , sulfate and magnesium those are the most harmful constituents in seawater, therefore when Attack on concrete due to any one of those constituents tends to increase the permeability; not only would this make the material progressively more susceptible to further action by the same destructive agent but also to other types of attack. Thus a maze of interwoven chemical as well as physical causes of deterioration is found at work when a concrete structure exposed to seawater is in an advanced stage of degradation [1].

As a construction material, concrete is the most economical and durable solution to marine structures, this is the reason to acquire knowledge of the interaction between seawater and the different mixes of Portland cement concrete during this project .

1.2 Problem Statement

1.2.1 Problem Identification

Plain concrete is a brittle material, it have low tensile strength and strain capacities. There is a general perception that concrete is a highly durable material.

Concrete exposed to marine environment may deteriorate as a result of combined effects of chemical action of seawater constituents on cement hydration products, alkali-aggregate expansion (when reactive aggregates are present), crystallization pressure of salts within concrete if one face of the structure is subject to wetting and others to drying conditions, frost action in cold climates, corrosion of embedded steel in reinforced or prestressed members, and physical erosion due to wave action and floating objects [2].

Since last 3 decades, improper durability of concrete particularly in marine environment has been a burning issue.

1.2.2 Significance of the Project

During this project the interaction between concrete and the marine environment will be further understood to signify the importance of choosing the right type of concrete mixes for longer serviceability of concrete in such corrosive environment. Moreover, during the manufacturing and experimental process, there is ample opportunity in getting the hands on experience and skills.

1.3 Objective and Scope of Study

The main objective of this project is study the interaction between concrete and the marine environment. The main goals are stated as follow:

i. To determine the effects of various cement replacement materials (CRM) on the total porosity of concrete.
ii. To determine the chloride diffusion profile with concrete age into various pozzolanic concrete.

1.3.1 Scope of Study

The project involves the preparation of an appropriate concrete mix design that incorporates cement replacement materials e.g. (fly ash and silica fume) and improves the resistance to chloride ingress; hence the service life in marine environment could be increased.

The experimental stage of this project involved the fabrication of concrete cubes (50mmx50mm) and (150mmx150mm) with seven different mixes. The concrete cubes with the dimensions of (150mmx150mm) are to be used for a compressive strength test, and the concrete cubes with the dimensions of (50mmx50mm) are to be used for two tests one test is specified for the chloride diffusion into the concrete cubes through submerging the samples in seawater for 2weeks, 6 weeks and 10 weeks. This test will help in the indication of concrete's ability to resist chloride and the other test is to measure the porosity of the concrete mixes.

CHAPTER 2

LITERATURE REVIEW

2.1 Marine Environments

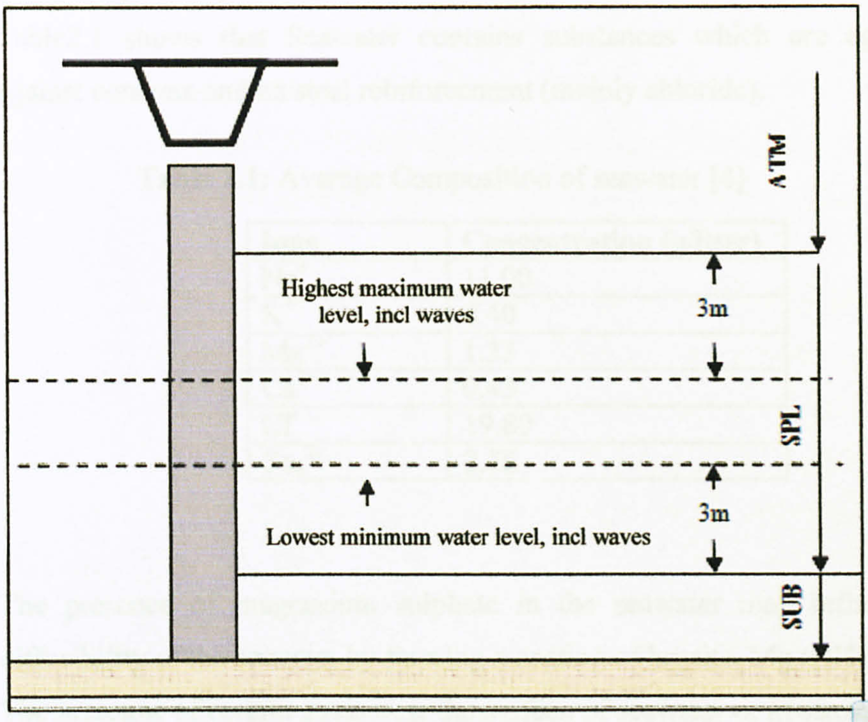


Figure2.1: A schematic illustration of various local marine environments. [3]

As in figure2.1. There are three environmental zones of marine exposure, as flows: [3]

i. Marine atmosphere, ATM concrete placed 3 m or more above the highest maximum water level. Concrete exposed to marine atmosphere can, if relevant, be subdivided into leeward and windward marine atmosphere.
ii. Marine splash, SPL. Concrete placed between 3 m above the highest maximum water level and 3 m below the lowest minimum water level inclusive of waves.
iii. Submerged in seawater, SUB. Concrete placed 3 m or more below the lowest minimum water level inclusive of waves.

2.1.1 Seawater

Most seawaters are fairly uniform in chemical composition, which is characterized by the presence of about 3.5 percent soluble salts by weight. The ionic concentrations of Na+ and Cl− are the highest, typically 11.00 and 19.80 g/liter, respectively.

Table2.1 shows that Seawater contains substances which are aggressive against concrete and its steel reinforcement (mainly chloride).

Table 2.1: Average Composition of seawater [4]

Ions	Concentration (g/liter)
Na^+	11.00
K^+	0.40
Mg^{2+}	1.33
Ca^{2+}	0.43
Cl^-	19.80
So_4^{2-}	2.76

The presence of magnesium sulphate in the seawater may influence the diffusibility of the concrete by forming a coating of brucite, $Mg(OH)_2$.

The presence of certain gases near the surface of seawater or in seawater plays an important roll in the chemical and electrochemical phenomena influencing concrete durability. Concrete exposed to sea water is susceptible to its corrosive effects. The effects are more pronounced above the tidal zone than where the concrete is permanently submerged. In the submerged zone, magnesium and hydrogen carbonate ions precipitate a layer of brucite, about 30 micrometers thick, on which a slower deposition of calcium carbonate as aragonite occurs. These layers somewhat protect the concrete from other processes, which include attack by magnesium, chloride and sulfate ions and carbonation [4].

Marine growth involving branches and mollusks is frequently found on the surface of porous concrete whose alkalinity has been greatly reduced by leaching. According to Hoff (1986), marine growth can also be a problem because it can produce increased leg diameter and displaced volume which would result in increased hydrodynamic loading. The additional surface roughness provided by the marine growth will increase the drag coefficient and will enhance the hydrodynamic loadings [4], [2].

2.1.2 Temperature

The surface temperature of seawater varies widely from a low of -2 °C in cold regions to a high of 30 °C in tropical areas. The temperature of seawater determines the rate of chemical and electrochemical reactions in concrete.

For concrete structures located in a warm climate, the heat may be an aggravating factor because heat is a driving energy source which accelerates both the onset and the progress of deterioration mechanisms. For each increase of 10 degrees Celsius in temperature, the rate of chemical reactions is doubled, which have a considerable impact on the rate of deterioration of concrete structures [5].

2.2 Concrete Composition and Properties

Concrete is a construction material composed of cement (commonly Portland cement) as well as other materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel, limestone, or granite, plus a fine aggregate such as sand), water, and chemical admixtures.

2.2.1 Composition of Concrete

Concrete is a complex of many components which solidifies and hardens after mixing them with water and placement due to chemical process known as hydration. Those components as described in table 2.2 are [6]:

i. Cement: Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar, and plaster. It consists of a mixture of oxides of calcium, silicon and aluminum.

ii. Water: combining water with a cementitious material forms a cement paste by the process of hydration. The cement paste glues the aggregate together.

iii. Aggregates: fine and coarse aggregates make up the bulk of a concrete mixture. Sand , natural gravel and crushed stones are mainly used for this purpose

Table 2.2: Composition of Concrete [7].

Typical composition by volume	
Cement	7-15%
Water	14-21%
Aggregate	60-80%

Figure 2.2, below is a cross section of concrete the two phases that can easily be distinguished are aggregate particles of varying size and shape, and the binding medium composed of an incoherent mass of the hydrated cement paste.

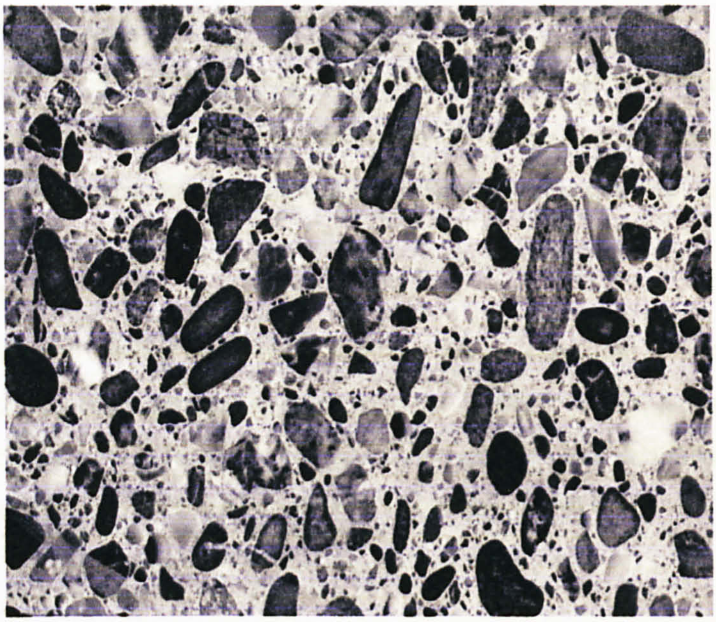


Figure 2.2: Section from a Concrete Specimen [7].

2.2.2 Properties of Concrete

Below are some properties of concrete which are in demand for modern sea structures:

i. **Strength :**

   The strength of a material is defined as the ability to resist stress without failure. Failure is sometimes identified with the appearance of cracks.

   Concrete has relatively high compressive strength, but significantly lower tensile strength. For that reason some concrete elements subjected to tensile stresses must be reinforced with materials that are strong in tension [8].

ii. **Elastic modules :**

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions.

iii. **Permeability :**

The permeability of concrete is one of the properties which is hard to measure and specify, although it plays an important role in determining the durability of materials in corrosive environments, such as seawater.

iv. **Durability :**

It's the ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. In other words, a durable concrete will retain its original form, quality, and serviceability when exposed to its intended service environment.[9]

2.2.3 Admixtures

Properties of concrete, in both the fresh and hardened states, can be modified by adding certain materials to concrete mixtures, those materials are known as admixtures. Admixtures vary widely in composition, from surfactants and soluble salts to polymers and insoluble minerals. Generally, they are used in concrete to improve workability, accelerate or retard setting time, control strength development, and enhance the durability to frost action, thermal cracking, alkali-aggregate expansion, sulfate attack, and corrosion of the reinforcement [9],[7].

Admixtures can be divided into two types as follows:

i. **Chemical admixtures:**

Materials in from of powder or fluids that are added to concrete to give it certain characteristics not obtained with plain concrete mixes .

in normal use, admixtures dosages are less than 5% by mass of cement and are added to concrete at the time of mixing .(i.e. $CaCl_2$, Plasticizers , Corrosion inhibitors etc).

ii. Mineral admixtures

Inorganic materials have pozzolanic or latent hydraulic properties. They can be added to improve the properties of concrete or as a replacement for Portland cement, such as fly ash and silica fume.

2.3 The process of chloride ingress

Chlorides, particularly calcium chloride, have been used to shorten the setting time of concrete. However, calcium chloride and sodium chloride have been shown to leach calcium hydroxide and cause chemical changes in Portland cement, leading to loss of strength, as well as attacking the steel reinforcement present in most concrete. [6]

Concrete is a material which liquids may penetrate. When concrete is exposed to chloride, the penetration of chloride occurs via the system of capillary pores, cracks and defects of the concrete. The transport mechanism is divided into the following groups [10], [3]:

i. Diffusion, where the transport of chloride is driven by the difference of the concentration of chloride in various zones. The chloride always diffuses into zones with smaller chloride concentration.

ii. Permeation, where chloride transport is driven by the difference of the hydraulic pressure in various zones. The chloride always moves into zones with smaller hydraulic pressure.

iii. Migration, where the chloride transport is driven by the difference in electrical potential. Chloride always moves into zones with less electrical potential.

2.4 Deterioration of Concrete in Seawater

Concrete exposed to marine environment may deteriorate as a result of combined effects of chemical action of seawater constituents on cement hydration products, alkali-aggregate expansion, crystallization pressure of salts within concrete if one face of the structure is subject to wetting and others to drying conditions, frost action in cold climates, corrosion of embedded steel in reinforced or prestressed members, and physical erosion due to wave action and floating objects. Attack on concrete by any of those causes will increase the permeability of concrete [2].

The causes of concrete deterioration are classified into two categories, physical and chemical causes respectively as shown in figure 2.3 and figure 2.4.

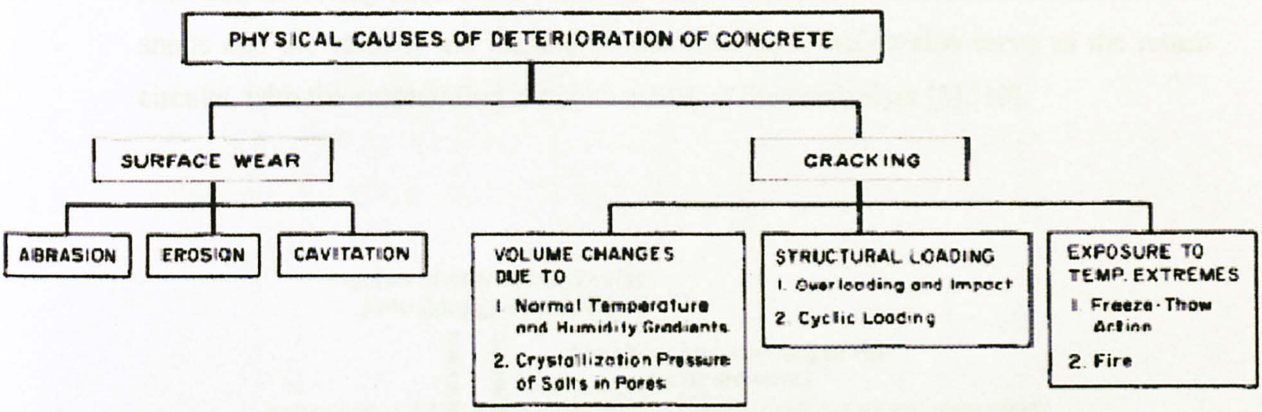


Figure 2.3: Physical Causes of Deterioration of Concrete [7].

Expansion and micro cracking due to physical effects in figure 2.3 of pressure from salt crystallization in a permeable concrete will increase the permeability further and pave the way for deleterious chemical interactions between seawater and cement.

2.5 Corrosion of Reinforcing Steel

When a concrete structure is exposed to deicing salts, salt splashes, salt spray, or seawater, chloride ions, those constituents will slowly penetrate into the concrete, mostly through the pores in the hydrated cement paste. As figure 2.5 shows the chloride ions will eventually reach the steel and then accumulate to beyond a certain concentration level, at which the protective film is destroyed and the steel begins to corrode, when oxygen and moisture are present in the steel-concrete interface. Once corrosion sets in on the reinforcing steel bars, it proceeds in electrochemical cells formed on the surface of the metal and the electrolyte or solution surrounding the metal. Each cell is consists of a pair of electrodes (the anode and its counterpoint, the cathode) on the surface of the metal, a return circuit, and an electrolyte. Basically, on a relatively anodic spot on the metal, the metal undergoes oxidation (ionization), which is accompanied by production of electrons, and subsequent dissolution. These electrons move through a return circuit, which is a path in the metal itself to reach a relatively cathodic spot on the metal, where these electrons are consumed through reactions involving substances found in the electrolyte. In a reinforced concrete, the anode and the cathode are located on the steel bars, which also serve as the return circuits, with the surrounding concrete acting as the electrolyte [5],[10].

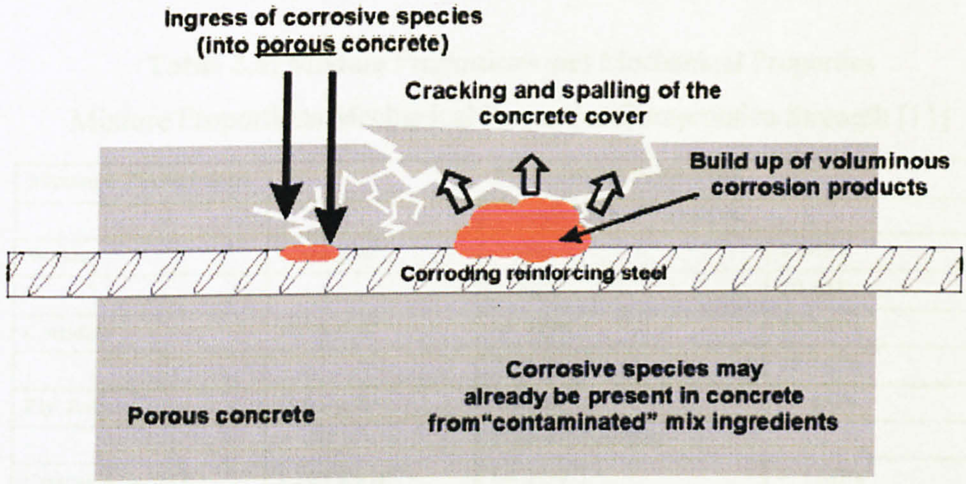


Figure 2.5: Corrosion of Reinforcing Steel [10]

2.6 Performance of Concrete in Marine Environment

In 1985 the Canadian Centre for Mineral and Energy Technology now called the International Centre for Sustainable Development of Cement and Concrete has shown that a 65% replacement by weight of cement with fly ash combined with a generous amount of super plasticizer provides excellent mechanical properties, low permeability, superior durability and low temperature rise during curing. This concrete system has been successfully used in high rise office buildings, sidewalks, streets and marine facilities. Typical mixture proportions and strength properties are given in Table 1. The high-volume fly ash system also has been used successfully for concrete, lightweight concrete and roller compacted concrete [11].

The below mixture will normally provide a slump of 180 to 220 mm and the autogenous temperature rise is normally sufficiently low that mass concrete with 65% fly ash will experience only a modest temperature rise. The early strength (i.e. at 1 day) is relatively low and as a result the concrete must be prevented from premature drying by moist curing for an adequate length of time.

Silica-rich supplementary materials such as fly ash, slag, silica fume, calcined diatomaceous earth, rice husk ash, and heat treated shale are all suitable candidates to replace Portland cement and at the same time enhance the properties of the concrete.

Table 2.3: Mixture Proportions and Mechanical Properties

Mixture Proportions Mechanical Properties Compressive Strength [11]

Mixture Proportions		Mechanical Properties	
		Compressive Strength	
Water	120 kg/m^3	1 day	8 MPa
		7 days	20 MPa
Cement	155 kg/m^3	28 days	35 MPa
		91 days	43 MPa
Fly Ash	215 kg/m^3	365 days	55 MPa
		Flexural Strength	
Coarse Aggregate	1,195 kg/m^3	14 days	4.5 MPa
		91 days	6.0 MPa
Fine Aggregate	645 kg/m^3	Modulus of Elasticity	
		28 days	35 GPa
A/E Admixture	200 mL/m^3	91 days	38 GPa
Superplasticizer	4.5 L/m^3		

As part of a long-term study on the performance of supplementary cementing materials in concrete, University of New Brunswick Fredericton arranged for the casting and placing of over 250 prisms 305X305X915 mm in size at a mid-tide wharf in the Bay of Fundy. The study is summarized as follows:

Table 2.4: Summary of the Long Term Study on the Performance of Concrete

Sample	Description	Conclusion	Photo
1	The effect of 25, 45 and 65% replacement of Portland Cement with ground pelletized slag in w/cm.0.4 air entrained concrete after 20 years exposure on a mid-tide wharf at Treat Island in the Bay of Fundy. Site is maintained by the US Corps of Engineers. Exposure 7300 cycles of wetting and drying and over 2000 cycles of freezing and thawing.	• At 25% replacement with slag-no effect material • At 45% and especially at 65% replacement significant loss of surface has occurred	
2	Effect of 80% replacements with ground granulation slag.	80% of replacement with ground granulated slag is comparable to 45% replacement with pelletized slag at 20 years at Treats Island.	
3	• Effect of 25% replacement with fly ash • Effect of 20% replacement with fly ash and effect of 40% replacement with pelletized slag • Effect of 20% replacement with fly ash and effect of 60% replacement with pelletized slag	• 25% replacement with fly ash – no effect • 20% replacement with fly ash along with either 40% or 60% pelletized slag results in significant surface distress at 20 years	

CHAPTER 3

METHODOLOGY

3.1 Process Flow

There are several steps need to be taken in order to achieve the objectives throughout the period of this study. The process flow of the project needs to be clarified and planned clearly at early stage to obtain the optimum results through understanding from the beginning until the end of the study. It is important to ensure the project will follow the certain guidelines or any restrictions if any to be completed parallel to the timeline.

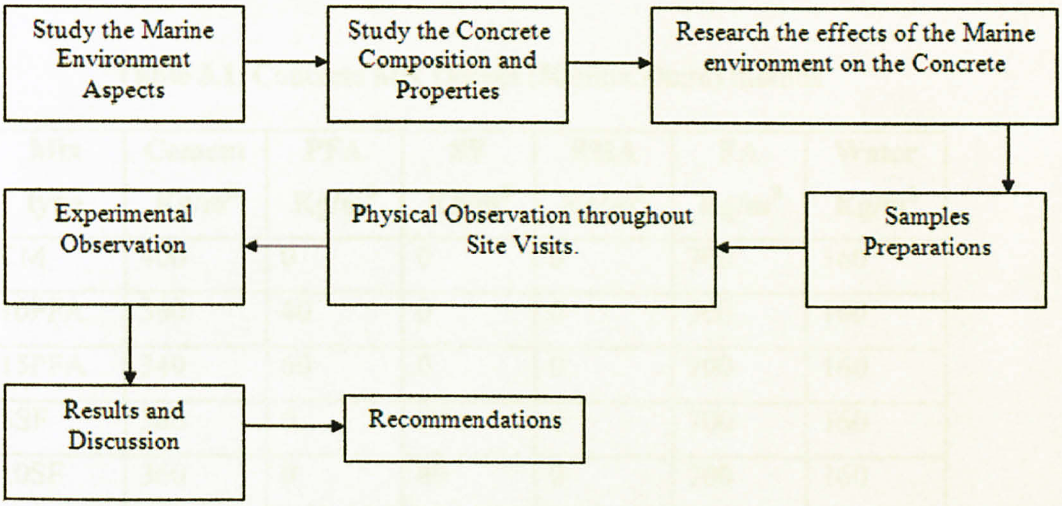


Figure 3.1: Flow Chart of the Study

The figure above shows the flow chart that was planned throughout the study period. For the first three steps, there is a need to understand the fundamentals of the marine environment and the basic components of concrete and its properties so that it is easy to correlate both concrete and the marine environment to understand and study the factors contributing to the deterioration of concrete.

The fourth step, sample preparations is done by the curing of different concrete mixes placed at (50mmx50mm) and (150mm x150 mm) moulds. The first concrete mix is shown in table 3.1 which was specified for the moulds (50mm x 50mm), this mix design does not contain aggregates. In the other hand table 3.2 shows the concrete mix design used for the moulds (150mmx150mm) which the mix design contain aggregates.

Cement 400 Kg/m^3 PFA Fly Ash

w/c 0.4 SF Silica Fume

FA Sand 700 Kg/m^3 RHA Husk ash

CA Gravel 1150 Kg/m^3 Maximum size = 10 mm

Table 3.1: Concrete Mix Design (50mmx50mm) moulds

Mix type	Cement Kg/m^3	PFA Kg/m^3	SF Kg/m^3	RHA Kg/m^3	FA Kg/m^3	Water Kg/m^3
CM	400	0	0	0	700	160
10PFA	360	40	0	0	700	160
15PFA	340	60	0	0	700	160
5SF	380	0	20	0	700	160
10SF	360	0	40	0	700	160
5RHA	380	0	0	20	700	160
10RHA	360	0	0	40	700	160

Table 3.2: Concrete Mix Design (150mmx150mm) moulds

Mix type	Cement Kg/m³	PFA Kg/m³	SF Kg/m³	RHA Kg/m³	FA Kg/m³	CA Kg/m³	Water Kg/m³
CM	300	0	0	0	750	1200	120
10PFA	270	30	0	0	750	1200	120
15PFA	255	45	0	0	750	1200	120
5SF	285	0	15	0	750	1200	120
10SF	270	0	30	0	750	1200	120
5RHA	285	0	0	15	750	1200	120
10RHA	270	0	0	30	750	1200	120

The fifth step is actually a site visit to Bashair II marine terminal in Port Sudan, a chance to get involved in a real construction project and lap tests on site. This will help determine the behavior of concrete mixes used in construction projects at marine environments. The results obtained from the site visit will be compared to those obtained from the sixth step, the experimental observation through lap tests. Three tests are conducted in order to measure chloride migration in the concrete, compressive strength of concrete samples used in this project and a porosity test.

3.1.1 Mixing of Concrete and Sample Preparation

➢ **Materials:**

Cement, coarse aggregate, fine aggregate water, and admixture proportioned per mix design. Weights of coarse aggregate, fine aggregate and water must be adjusted for aggregate moisture contents on day of batching (field mix design).

➢ **Apparatus:**

I. Concrete Mixer.

II. Molds , (50mmx50mm) and (150mmx150mm)

III. Concrete vibrator

IV. Vibratory Table

V. Curing tank

VI. scoop or trowel

VII. shovel

➢ **Procedure:**

1) Coarse and fine aggregate are dampened.
2) Half of the water is added.
3) Mixer is started and mix for 1 minute.
4) Mixer is stopped and waited for 8 minutes.
5) Cement and admixtures are added were applicable.
6) Mixer is started again.
7) The rest of the water is added.
8) Mix for 1 minute.
9) The concrete is poured into a clean and wet wheelbarrow.
10) Concrete stuck in the mixer is removed using a scoop or trowel.

➢ **Sample preparation:**

1) The concrete is placed in the cubical molds as shown if figure 3.2, using hand trowel or scoop, in three layers, each approximately one third the volume of the mold. For the final layer, sufficient concrete is placed to just fill mold after compaction (using concrete vibrator).
2) The sample is let for 24 hours to dry.
3) The molds are removed and the samples are placed in the curing tank for 28 days as shown in figure 3.3.

Figure 3.2: Concrete Cubical Molds

Figure 3.3: Curing Tank

3.2 Experimental Tools

The those are used for the fabrication and curing process of the concrete mixes .

3.2.1 Concrete mixer

The concrete mixer is ideal for both wet and dry cast concrete, it offers a fast and reliable mixing The mixer contains a serious of individual mixing arms which are carefully positioned to both move the material from the hub of the mixer to the wall and back whilst also folding the material over itself during the process.

3.2.2 Concrete Vibrator

Concrete vibrators are used to consolidate fresh concrete so that entrapped air and excess water are released and the concrete settles firmly in place in the formwork. Improper consolidation of concrete can cause product defects, compromise the concrete strength, and produce surface blemishes such as bug holes and honeycombing. An internal concrete vibrator is a steel cylinder about the size of the handle of a baseball bat, with a hose or electrical cord attached to one end. The vibrator head is immersed in the wet concrete.

Figure 3.4: Concrete Vibrator

3.3.3 Vibrating Table

The Vibrating Table is ideal for vibrating concrete beam forms, cylinder molds and manufactured concrete products. The table will handle loads up to 300 lbs. (136 kg).The high-speed (3,600 Vpm) of these tables, coupled with a controlled low-amplitude that does not exceed 1/16" (1.58 mm) linear vibration, produces a gentle settling action. Through this action, the coefficient of friction of the material is reduced. As the material settles, the entrapped air is more readily removed.

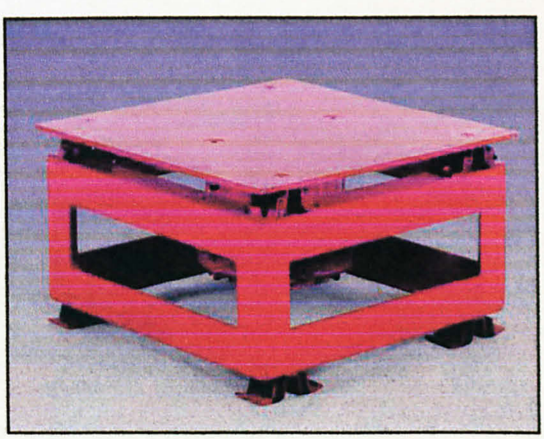


Figure 3.5: Vibrating Table

3.3.4 Mortar Mixer

The ELE Automatic/Manual Mortar Mixer shows in figure 3.6 enables carefully controlled cement mortar mixes to be prepared. The machine's mixing paddle and bowl have been specially designed in accordance with industry standards, to avoid breaking down the sand particles that could affect the final strength. Sand and water can be easily added at the appropriate time.

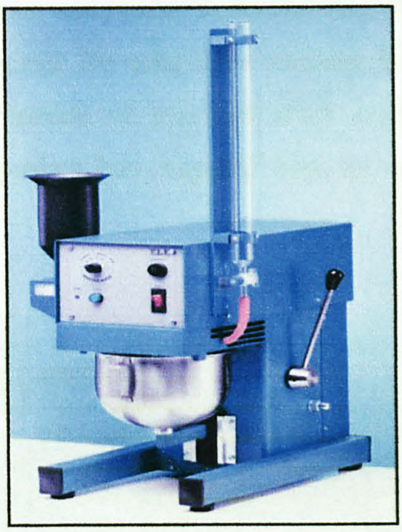


Figure 3.6: Mortar Mixer

CHAPTER 4

ON SITE INVESTEGATION

Correlation to the research work of the project and as planned; the author had the chance during the semester break to visit BASHAIR II marine terminal in Port Sudan (figure 4.1), this marine terminal belongs to Petrodar Operating Company (PDOC) in Sudan one of the biggest oil and gas operating companies.

The visit gave the chance towards better understanding of the level of professionalism and communication required for long-term success in the field. The author also confident that his combination of practical work experience and solid education experience through his project has prepared him for an immediate contribution to working life.

Figure 4.1: Bashir II Marine Terminal, Port Sudan

The visit lasted for 3 weeks , within those weeks the author was involved in the construction of a warehouse at the marine terminal , also a chance were given to do some lab tests on concrete.

4.1 Warehouse construction marine terminal

4.1.1 Introduction

PDOC Marine Terminal is located at the coastal area nearby Port Sudan, which was designed to deliver the crude oil through the pipeline system with a storage capacity of 3 million bbl. The crude oil loading facilities include a Single Point Mooring (SPM) buoy with the loading capacity of 5 million bbl/day connected by 2 x 36" subsea pipelines. The SPM is located two kilometer away from the beach.

PDOC proposed to construct a warehouse to keep all the equipments and spare parts needed for the smooth running of the marine terminal. The ware house has an area of 60 x 20m which quite large enough to accommodate all the required equipments.

The project is wholly own by Petrodar operating Company, PDOC and the contractor for the project is Elda woody Engineering company.

4.1.2 Foundation

The foundation type used in the ware house is a pad foundation. Pad foundation is used because the soil is sufficiently strong and stiff to support the imposed loads and it has low compression ability. The characteristic strength of the concrete is 25 N/mm^2. There are a total of 22 pad foundations constructed at an interval of 7.5m to sustain the load of the building

4.1.3 Foundation reinforcement

According to the design and as figure 4.2 shows the tension steel at the base of the foundation has a diameter of 16mm at an interval of 150 mm center to enter (Ø16@150 c/c). The stirrup has diameter of 8mm place d at an interval of 150 center to center (Ø8@150 c/c).

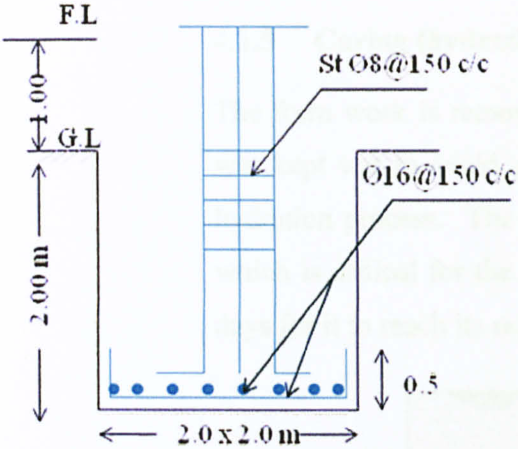


Figure 4.2: foundation detailing

Table 4.1: foundation detailing

Item	Diameter (Ø)mm	Spacing c/c
Tension bar	16	150
Compression bar	16	150
stirrup	8	150

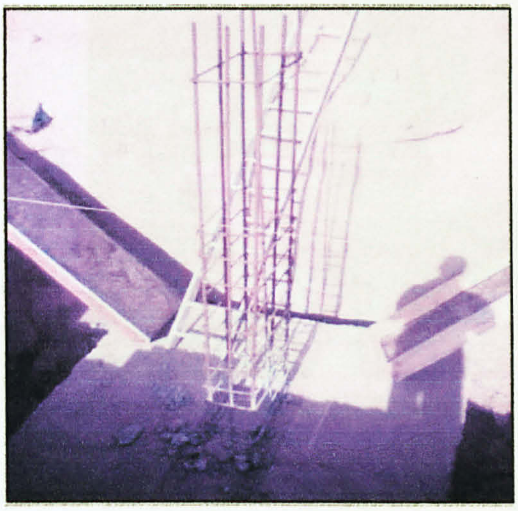


Figure 4.3: Column Reinforcement

4.1.4 Foundation Casting

After finishing the reinforcement, the foundation is casted. The water cement ration used in the mix is 4:2:1 (four coarse aggregate, two fine aggregate, and one cement) to give the required strength which is 25 N/m.

The coarse aggregate size used in the casting is 20mm, and the cement type is sulphate-salt resistant cement. The building is few meters from the sea; therefore the foundation is vulnerable to sulphate attack thus, SRC has to be used to prevent damage to the foundation.

4.1.5 Curing (hydration)

The form work is removed after 24 hrs. Figure 4.4 shows the column which was kept wet to avoid any water lost from the column which will affect the hydration process. The column was kept intensively wet for the first 3 days which is critical for the strength development of the concrete. And another 7 days for it to reach its required characteristic strength of 25 N/mm^2

Figure 4.4: curing (hydration process)

4.1.6 Concrete Coating

Water plays a significant role in many concrete degradation mechanisms. It carries dissolved salts into the concrete, dissolved carbon dioxide which results in carbonation, and water is a requirement for the corrosion of embedded steel. Coatings reduce the amount of water infiltration into the concrete by covering surface pore openings in the concrete to reduce water infiltration. The coating of the concrete in Port Sudan is vital because of the sea water which contains salt (sulfur).

After 7 days of intense curing, the concrete column had to be coated with aquashield BX bitumen emulsion coating.

➢ **Aquashiel BX bitumen**

Aquashield BX (Figure 4.5) is a heavy duty non-fabricated general purpose water-proofing bitumen emulsion coating equally formulated to provide high vapor permeability with very high resistance to re-emulsification.

Figure 4.5: Bitumen coat

➢ **Application**

Figures 4.6 and 4.7 shows the coating of bitumen which was applied on the concrete surface .After preparing the surface with Bitufast primer, the first coat was applied with brush on dry surface. On drying, the second coat for reinforcement was then applied.

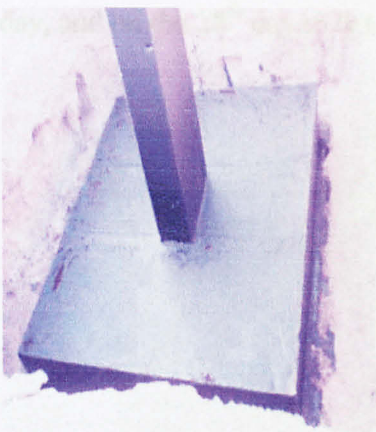


Figure 4.6: First layer coating

Figure 4.7: Second layer coating

4.2 Tests Conducted on The Concrete

4.2.1 Cube test

The Concrete cubes are made on site to check that the strength of the concrete is above the minimum strength which has been specified. Making, curing and testing cubes should be carried out in the correct manner. Even small deviations from the standard procedures will usually lead to compressive strength results which are lower than the true strength of the concrete. For each 1% air entrapped there will be a 4 to 5% loss of strength.

- **Equipment Used :**

1. Sample tray;
2. Mould for making test cube;
3. Spanners;
4. Scoop;
5. Steel float or trowel;
6. Compacting bar;
7. Vibrating hammer or vibrating table;
8. Cleaning rags;
9. A bucket or barrow for transporting the samples;
10. Polythene sheeting;
11. Curing tank.

After demoulding the cubes, the concrete cubes were taken to the nearby lab in Port Sudan for curing and testing. The tests were conducted on the 3rd day, 7th day, and on the 28th day to determine the strength development progress.

Figure 4.8: curing process

Figure 4.9: cube testing

- **Test Results :**

As seen in the table 4.2 below, the strength development of the concrete is increasing gradually with time. It achieved 80% of the required strength (25 N/mm^2) in the first 3 days and only on the 7^{th} day it exceeded the required strength which was a positive indication. It shows that there were no errors done during its workable period (mixing, placing, and compacting)

Table 4.2: Compressive strength test result for the foundation

Concrete Age , Days	**3 days**	**7days**	**28 days**
Compressive strength N/mm^2	18	26.1	34

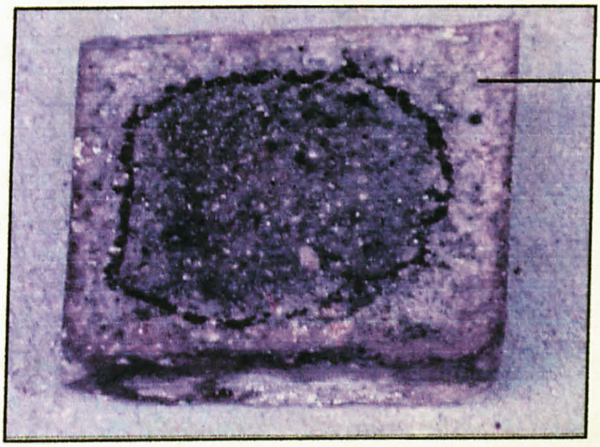
Design strength = 25N/mm^2

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Chloride Diffusion Test

This test is desired to measure the chloride ingress in concrete samples with respect to time. Concrete samples are prepared as shown in 3.1.1 with some few modifications. The concrete samples used in this test are mortar samples which do not contain aggregates placed in (50mmx50mm) molds; the mix design is shown in table 3.1. The samples then are put in the curing tank for 28 days, after that the samples are placed in seawater for 2 weeks, 6 weeks and 10 weeks. The test is conducted by breaking the concrete sample into two pieces and sliver nitrate ($AgNo_3$) is applied to the surface of the broken samples. As shown in figure 5.1 $AgNo_3$ will show the area of the concrete sample affected by the chloride diffusion. Chloride profiles are then measured.



Area of Chloride Diffusion

Figure 5.1: Chloride Diffusion in Concrete

Results were obtained for the samples of the ages of 2 weeks, 6 weeks and 10 weeks. Table 5.1 and figure5.2 below shows the results obtained.

Table 5.1: Results of Chloride Diffusion Test

Mix Type	Chloride Diffusion into Concrete, cm		
	2 weeks	6 weeks	10 weeks
CM	1.2	1.35	1.68
10PFA	1.14	1.25	1.49
15PFA	0.7125	1.10	1.20
5SF	1.175	1.23	1.41
10SF	1.05	1.15	1.34
5RHA	1.088	1.20	1.45
10RHA	0.79	1.27	1.37

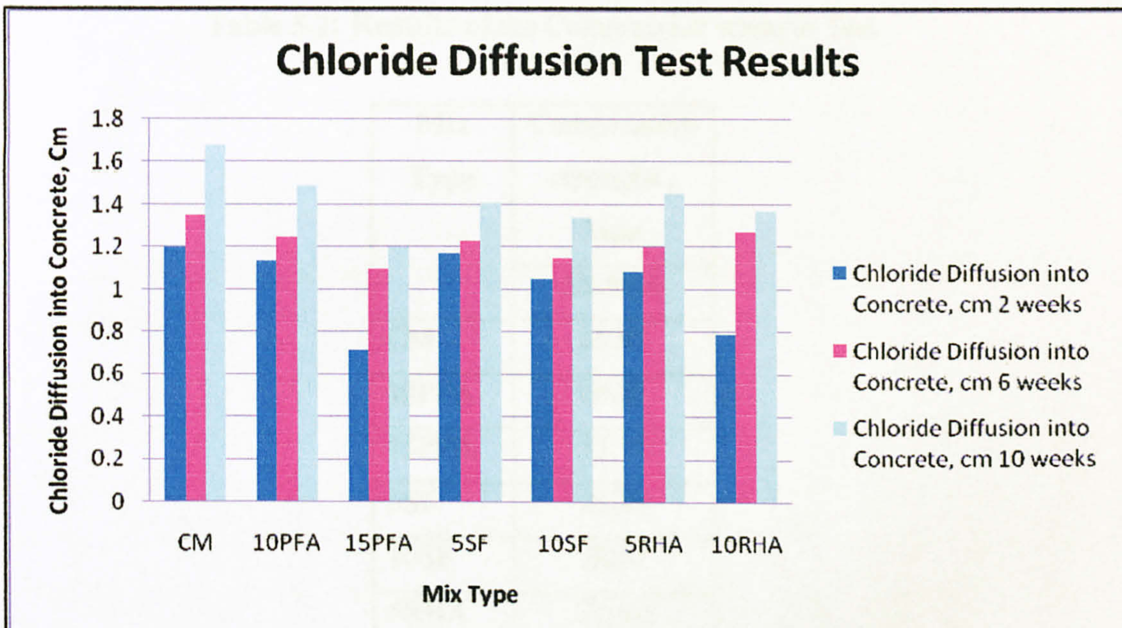


Figure5.2: Chloride Diffusion VS Concrete age

5.2 Compressive strength test

Compressive strength is the capacity of a material to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. Concrete can be made to have high compressive strength. [1], [12]

During this test concrete mixing and sample preparations are the same as in 3.1.1, the molds for the compressive test samples are (150mmx150mm) and the mix design is shown in table 3.2. Notice that during this mix design coarse aggregates are used.
After the samples are prepared and cured for 28 days the specimens are then put in the compression testing machine. Minimum of 3 compressive tests are made for each mix. The results obtained as shown in table 5.2 and figure 5.3 below.

Table 5.2: Results of the Compressive strength Test

Mix Type	Compressive strength, Mpa
	28 days
CM	15.97
10PFA	16.41
15PFA	33.17
5SF	21.89
10SF	28.47
5RHA	20.10
10RHA	22.10

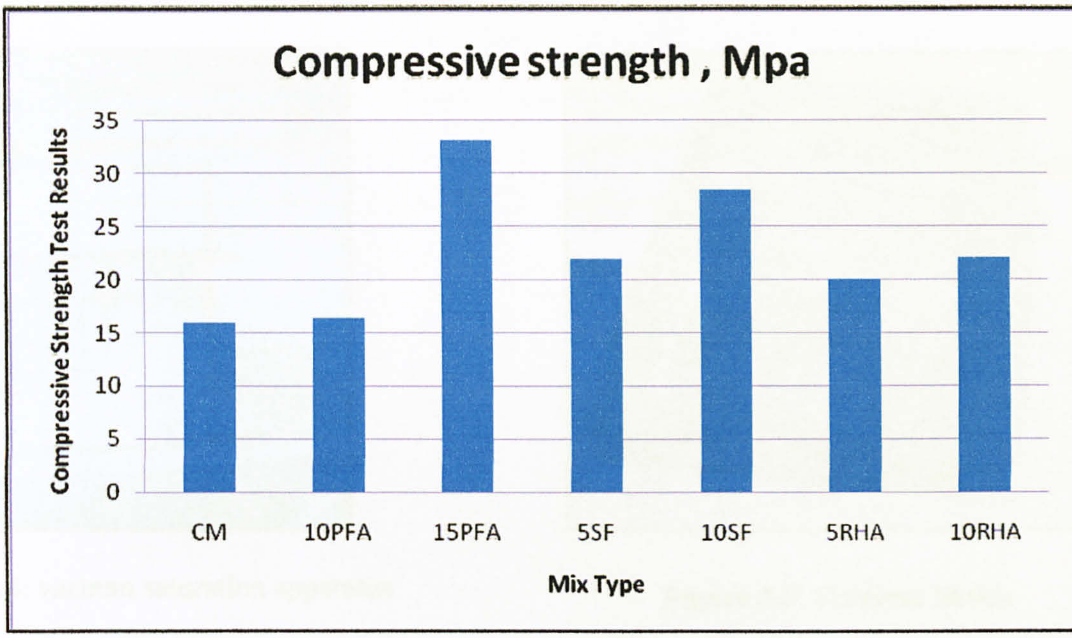


Figure5.3: Compressive Strength Results

5.3 Porosity Test

The test is desired to calculate the porosity of the concrete using a vacuum saturation apparatus figure 5.4.

The samples are prepared as in 3.1.1. Figure 5.5 shows the molds used for preparing the samples for this test. The mix design is shown in table 3.2.

After the samples are cured we will core 3 specimens from each mix those specimens will be put inside the apparatus and run the vacuum pump for 30 min, then water will be added and the pump will run for 6 hours, we leave the sample for an overnight. Later samples will be weight in air (WSA) and in water (WSW). Then the samples will be put in an oven at 100° C for 24 hours, later samples will be weight (WD).

Porosity (P) will be calculated using the equation in 5.1.

$$P\% = \frac{WSA - WD}{WSA - WSW} \times 100\% \qquad (5.1)$$

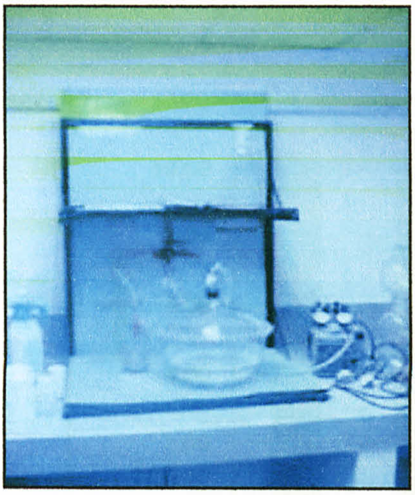


Figure 5.4: vacuum saturation apparatus

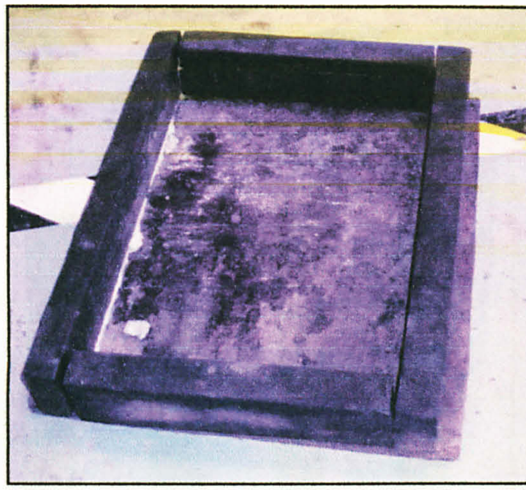


Figure 5.5: Concrete Molds

Results obtained are as shown below in table 5.3 and figure 5.6 .

Table 5.3: Results of the Porosity Test

Mix Type	Samples weight , g			
	W_{SSD}	W_W	W_{OD}	P%
CM	132	31.25	121.4	10.52
10PFA	120.2	32.7	111.4	10.06
15PFA	118.2	42.3	110.2	10.54
5SF	126.3	35.8	118.6	8.51
10SF	125.5	43.4	116.4	11.08
5RHA	114.8	30.5	107	9.25
10RHA	119.55	35.13	112.4	8.47

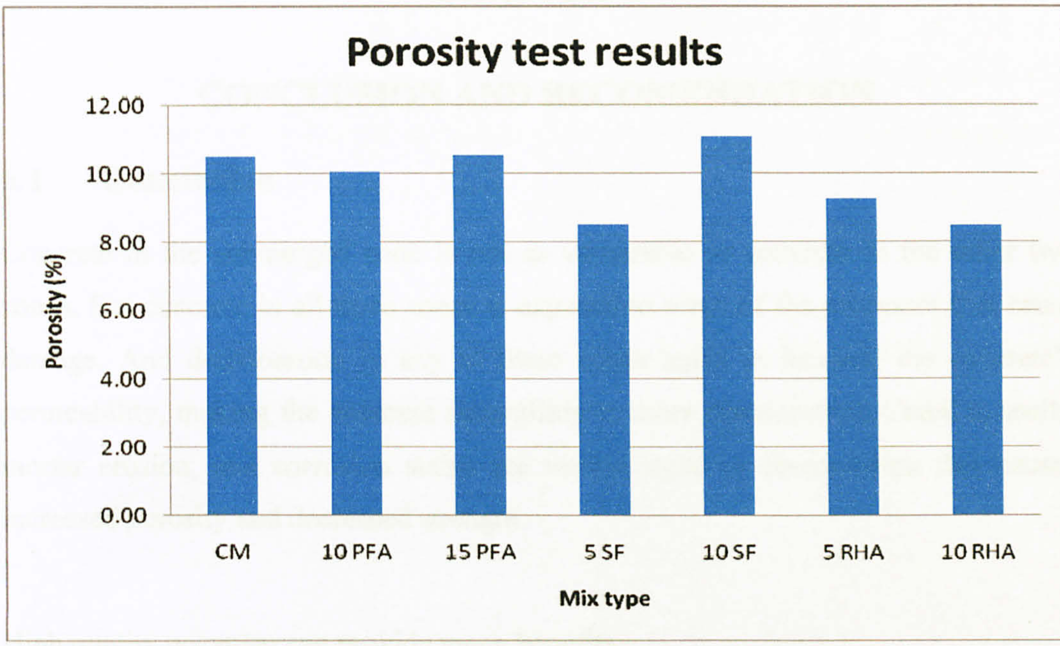


Figure 5.6: Porosity Test Results

CHAPTER 6

CONCLUSION AND RECOMENDATION

6.1 Conclusion

Concrete in the submerged zone is not as vulnerable as concrete in the other two zones. But concrete in all three zones is exposed to some of the processes that cause damage. And deterioration in any of these zones tends to increase the concrete's permeability, making the concrete susceptible to more deterioration. Crack s, spalls, mortar erosion, and corrosion stains are visible signs of deterioration that causes increased porosity and decreased strength.

High quality pozzolan can provide many benefits:

- Increased strength
- Reduced permeability

Fly ash and silica fume are the most common pozzolans used in concrete mixtures for marine environments. A pozzolan combines with the calcium hydroxide and water in the mix to form hardened cementitious products .These hydrated products increase the strength and reduce the permeability of the concrete

Based on the results obtained from the experimental observations 15 PFA have been found to have the most optimum mix design to resist the sever conditions of marine environment manly the chloride diffusion as shown in table 6.1 .

Table 6.1: The Most Optimum Mix Design

Mix type	Compressive strength , Mpa	Porosity %	Chloride Diffusion after 10 weeks , Cm
15 PFA	33.17	10.54	1.20

Comparing the results obtained from the experimental observations and the data collected from the site visit, we found that 15 PFA mix type can be implemented on the construction site in Bashair II marine terminal instead of the mix type used there for several reasons :

1. The cement type used at the site is sulphate-salt resistant cement which is expensive.
2. The compressive strength test for the mix 15 PFA shows better results than the mix of sulphate-salt resistant cement.
3. The use of aquashiel Bx bitumen is not necessary while using the mix of 15 PFA since the results obtained during the chloride diffusion test and porosity test showed resistivity to the sever conditions of marine environments

6.2 Recommendation

It is recommended to explore further on the effects of the marine environments on concrete considering other constituents such as Mg^{2+} and Na^{+}.
Further the study will help better understanding of the interaction of concrete with the marine environment; hence a better mix design will be obtained to achieve long serviceability for concrete structures in the marine environment

REFERENCES

1. Lea, F. M., The Chemistry of Cement and Concrete, 3rd edn, Chemical Publishing Co., New York, 1971.
2. Gerwick, B. C., Construction of offshore structures, Wiley- Interscience,1986,pp. 64-5.
3. Callister W.D. Jr., Materials Science & Engineering an Introduction, John Wiley & Sons, 2003 U.S.A
4. Kejin Wanga, Daniel E. Nelsena and Wilfrid A. Nixon, "Damaging effects of deicing chemicals on concrete materials", Cement and Concrete Composites Vol. 28(2), pp 173-188
5. Hoff, G.C., The service record of concrete offshore structures in the north sea, Proceeding, International Conference on concrete in the marine environment, The Concrete Society, London, 1986, pp.131-42
6. Kejin Wanga, Daniel E. Nelsena and Wilfrid A. Nixon, "Damaging effects of deicing chemicals on concrete materials", Cement and Concrete Composites Vol. 28(2), pp 173-188
7. .McGrath Patrick F. Development of test methods for predicting chloride penetration into high performance concrete. PhD thesis, Department of Civil Engineering, University of Toronto, Canada; 1996
8. Federiksen, Nilsson,Sandberg, Poulsen, Tang and Anderson, 1997, HETEK, a system of estimations of chloride ingress into concrete, theoretical background. Report No.83:1997.
9. Lea, F. M., The Chemistry of Cement and Concrete, 3rd edn, Chemical Publishing Co., New York, 1971.
10. . Mays et al., 1992, Durability of concrete structures, investigation, repair, protection. E&FN SPON, London UK 1992.
11. Bilodeau, A. and V.M. Malhotra, "High-Volume Fly Ash System: The Concrete Solution for Sustainable Development", in CANMET/ACI International Symposium on Sustainable Development ofthe Cement and Concrete Industry, editor V.M. Malhotra, Ottawa, Oct. 21- 23, 1998, pp. 193-214

12. Performance of Concrete at Treat Island, USA: CANMET Investigation" by V. Mohan Malhotra and Theodore W. Bremner, in the Proceedings of the Third CANMET/ACI International Conference held at Saint Andrews by the Sea, NB, Canada. V.M. Malhotra, Ed. ACE SP-163, 1996, pp 1-52.
13. Kosmatka, S.H.; Panarese, W.C. (1988). Design and Control of Concrete Mixtures. Skokie, IL, USA: Portland Cement Association. .
14. Metha, P.K, Concrete: Structure, Properties, and materials, Prentice Hall, Englewood Cliffs, NJ, 1986.
15. P.Kumar Mehta & Paulo J.M. Monteiro. Concrete: Microstructure, Properties and Materials

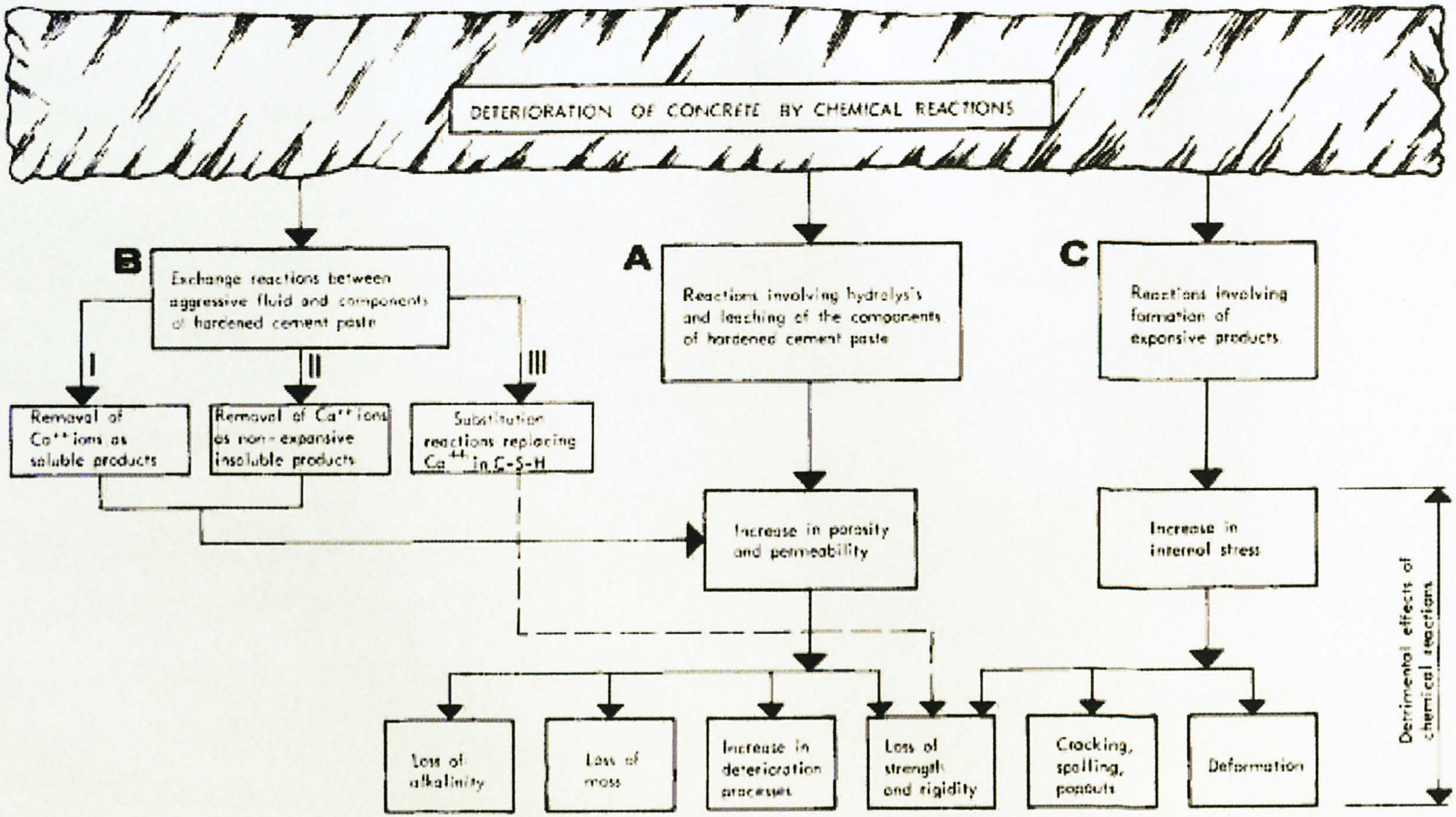


Figure 3.4 : Chemical reaction Responsible for concrete Deterioration [10]