

## Strength behavior of concrete using slag with cement in sea water environment

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Received 27 June 2010

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### Abstract

This paper investigates the performance of slag concrete exposed to artificially made sea water. Concrete specimens of 100 mm cubical size were cast and precured for 30 days in plain water before exposure to different seawater environments. Physical aspects regarding the deterioration of OPC and slag concrete of cement slag mix ratio 85:15, 70:30 and 55:45 have been studied in plain water and seawater of salt concentration 1N, 3N and 5N over the periods of 1, 3, 6 and 12 months. The specimens were taken out periodically and subjected to compressive strength and ultrasonic pulse velocity tests. From the investigation, it has been revealed that slag concrete of cement slag mix ratio 70:30 has better resistance against strength deterioration for all curing conditions and curing ages. It is primarily due to high fineness of slag, which after hydration markedly reduce the permeability of concrete that restrict the penetration of sea salt. Slag concrete of mix ratio 70:30 with water cementitious ratio 0.4 and 30 days precuring is found to be the most effective in resisting the adverse effect of sea water.

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*Keyword:* Slag, OPC, Marine Environment, Chloride attack, Compressive Strength, Ultrasonic Pulse Velocity, Mix proportion.

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### 1. Introduction

Cement, mortar and concrete are the most widely used construction material all over the world. It is difficult to find out alternate material for construction which is as suitable as that of such material from durability and economic point of view. The expanded uses of concrete have increased the interest of scientists / researchers for its use in aggressive environments such as marine environment. A well designed concrete structure can survive up to its design life without any major repair / maintenance work in adverse surrounding environment. Good quality concrete provides excellent protection to the

embedded steel reinforcement against corrosion. Chemical protection is provided by high alkalinity of the concrete and the physical protection is afforded by the cover concrete which acts as a barrier to the access of aggressive species [1].

Marine environment indicates the environment surrounded by the seawater. Sea water (SW) is a complex solution of many salts containing living matter, suspended silt, dissolved gases and decaying organic material. The average salt concentration of sea water is about 3.5% although it varies from sea to sea depending upon geological location (e.g. Table 1). But the complexities inherent in such an environment are not usually clear. It is not just over the sea, rather extended over the coast and the neighborhood of tidal cracks, backwaters and estuaries. Broadly, it covers the area where concrete becomes wet with seawater and wherever the wind will carry salt water spray which may be as far as 1 km inland [2]. Concrete structures located in such an environment are always subjected to aggressive loadings both physical and chemical in nature over their entire life span. The physical actions consisting of various loadings caused due to cyclic sea waves, high and low tides, ocean currents, hydrostatic pressure, freeze thaw cycles, temperature gradient etc, have their own independent damaging effects on the exposed concrete structures [3]. While the chemical actions consist of slow decomposition of cement mortar matrix and corrosion of the embedded reinforcement due to the reaction of various salt ions present abundantly in sea water [4]. The external action includes physical actions like freezing-thawing, alternate wetting-drying and also the mechanical actions like abrasion, salt water spray, cyclic drag etc. The internal actions cause the deterioration of concrete due to penetration of salt ions into its various depths. Hence prior to the construction of any concrete structure in such location, proper steps should be taken to overcome the risk of deterioration of concrete due to chloride, sulfate and other sea salt ion attack.

Depending on the tidal range, nature, extent and mechanism of deterioration process, a reinforced concrete structure exposed to a marine environment can be divided into different zones like Atmospheric zone, Splash zone, Tidal zone and Submerged zone (Ref. Figure 1). The atmospheric zone is the upper most part extending upwards from the splash zone. In this zone, the air is heavily laden with moisture containing substantial quantities of salts and gases. Due to temperature variation and wave action, freeze-thaw cycles may occur in some oceans. The splash zone extends upwards from the tidal zone and is the most critical area for offshore structures due to erosive effect of continuous salt water spray and wave action in presence of atmospheric  $O_2$  and  $CO_2$ . The tidal zone experiences alternate wetting and drying action in seawater and is considered as the second most corrosive area. The submerged zone is defined as that lying between low water level and above the bed. The hydrostatic pressure increasing with depth can cause rapid penetration of harmful salt ions into the concrete and is regarded as the least corrosive zone due to non availability of  $O_2$  and  $CO_2$ .

In most of the concrete structures, seawater, soil containing sulfate bearing fertilizer, industrial effluents, acid rain, and ground water may cause chloride and sulfate attack on reinforced concrete [5,6]. In aqueous environments, chloride and sulfate ions penetrate into the interior of concrete structure and start chemical reaction. As a result, many complex reactions occur which leads to physical and chemical changes within the concrete [7]. In these consequences, the deterioration of concrete takes place in the form of discrete surface cracks, concrete spalling and corrosion of reinforcement [8]. Permeability is another important property for durability of concrete. Improper mix proportioning may lead to permeable concrete that tends to deteriorate in marine environment [9]. This is due to the fact that the hydration products of Portland cement

becomes unstable in certain aggressive salt ion component present in sea water. Complete understanding of the mechanism of salt attack in concrete matrix and embedded rebar is therefore bears great importance for research activities in marine constructions [10].

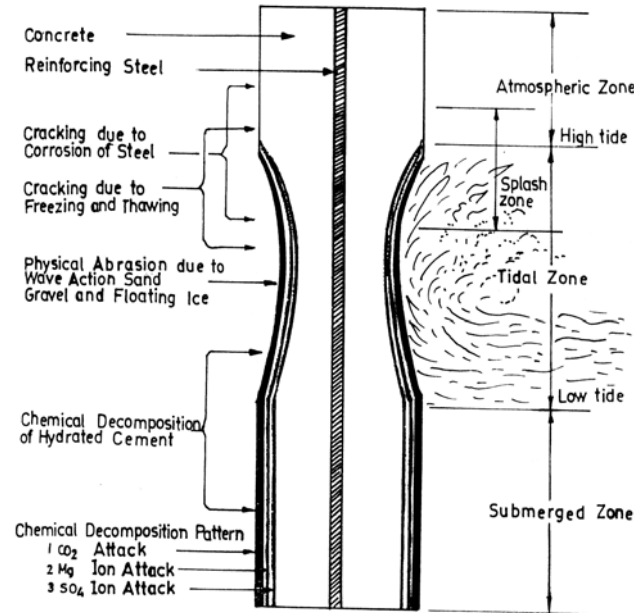
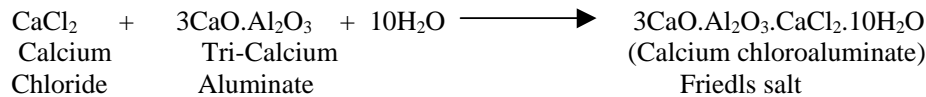
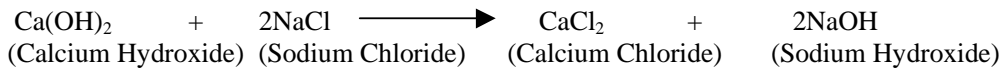


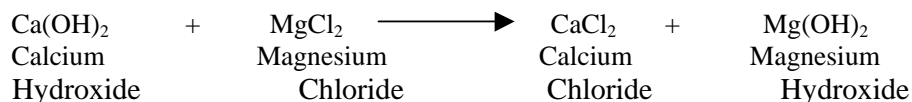
Fig. 1: Deterioration of Concrete Structure in Marine Environment [30]

Chloride ions may cause adverse effect on hardened concrete in variety of ways. It may attack concrete in also different forms. It is generally attributed to the formation of expansive product named Friedls salt ( $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{CaCl}_2\cdot 10\text{H}_2\text{O}$ )(Calcium chloroaluminate). This salt has a property of low to medium expansion. Also the formation of excess calcium chloride, which may leach out, results in increased permeability of concrete.

The process of chloride attack on concrete may be explained by the following series of chemical reaction [11, 12]



According to Metha (1986) [13],  $\text{MgCl}_2$  after reacting with  $\text{Ca(OH)}_2$  of hydrated cement forms calcium chloride, which being soluble, gets leached out leading to material loss and weakening. Possible reactions are given below:



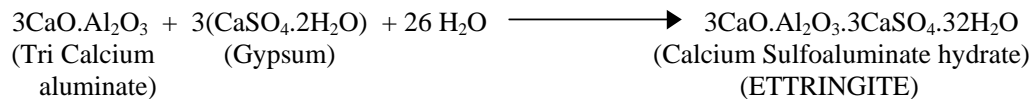
Sulfate attack is generally attributed to formation of expansive ettringite ( $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{CaSO}_4\cdot 31\text{H}_2\text{O}$ ) (Calcium aluminate sulfate). Both ettringite and gypsum occupy a greater volume as large as 20% after crystallization in the pores of concrete than the compounds they replace. Thus the crystalline product inducing stresses inside the concrete may resulting the surface cracking known as softening type of attack.

Table 1  
Average Salt Concentration in Different Seas [28]

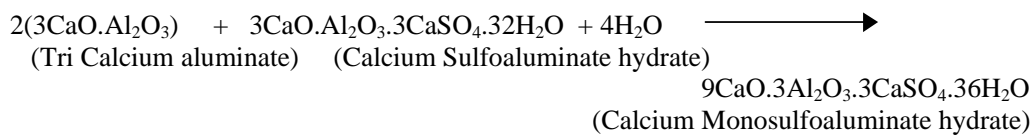
Sea	Salt Concentration (%)
Mediterranean	3.8
Baltic	0.7
North sea and Atlantic	3.5
Black Sea	1.8
Dead Sea	5.3
Indian Sea	3.55

The process of sulfate attack on concrete may be explained by the following series of chemical reactions:

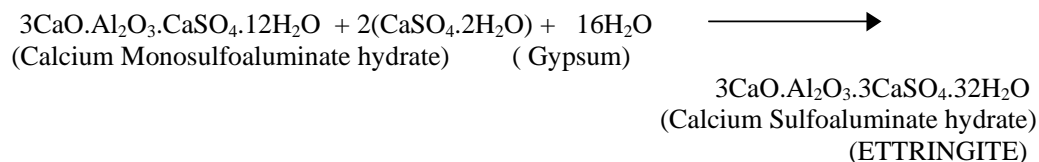
In Portland cement the hydration of  $\text{C}_3\text{A}$  involves reaction with sulfate ions which are supplied by the dissolution of gypsum [14]. Initial reaction of  $\text{C}_3\text{A}$  is,



This calcium sulfoaluminate hydrate, whose correct name is 6-calcium aluminate trisulfate-32-hydrate, is commonly known as ettringite. This is often written as  $\text{C}_3\text{A}\cdot 3\text{CSH}_{32}$ . Ettringite is stable. If the sulfate is all consumed before  $\text{C}_3\text{A}$  is completely hydrated then ettringite transforms to monosulfoaluminate.



When this monosulfoaluminate is brought in contact with new source of sulfate ions, then Calcium Sulfoaluminate hydrate (ettringite) can be formed once again



In a marine environment, chloride ion and sulfate ion penetrating into the concrete from sea water forming calcium chloroaluminate (Friedels Salt) and calcium sulphoaluminate (Ettringite). Both the products occupy a greater volume after crystallization in the pores of concrete than the compounds they replace. The formation of gypsum hydrate causes an increase in volume of 17.7% in concrete [15].

Deterioration of concrete due to chloride and sulfate attack is a time-dependent problem. These salts react with various hydration products and form detrimental voluminous

compounds, which results in expansion and eventually cracking and spalling of concrete. Both chloride and sulfate induced deterioration of concrete are the subject of main interest for researchers dealing with durability and long-term performance of concrete. The ionic radii of chloride and sulfate ions are 1.81 Å and 2.30 Å respectively [16]. Also the diffusion coefficient for sulfate is  $2 \times 10^{-8} \text{ cm}^2 \text{ S}^{-1}$  and for chloride is  $3 \times 10^{-7} \text{ cm}^2 \text{ S}^{-1}$  [17]. Due to larger diffusion coefficient, chloride ions penetrate at a faster rate than that of sulfate. On the other hand as sulfate holds two negative ions higher than that of chloride (one negative ion), its action on deterioration is more dangerous. Thus both chloride and sulfate penetration may have detrimental effects on concrete exposed to marine environment.

Concrete mixes prepared by supplementary mineral admixtures such as Slag, Fly ash, Silica fume as partial replacement of ordinarily Portland cement gives new idea to reduce permeability of concrete [18]. These mineral admixtures may impart proper resistance to chloride and sulfate induced deterioration by modifying the chemistry of pore characteristics of the hardened concrete [19]. Fineness of these particles is higher than ordinary Portland cement particles [20]. As a result, it may produce denser concrete that finally makes concrete more impermeable, which may greatly reduce penetration of chloride and sulfate ions, thereby increasing the durability of concrete [21]. They react with the product liberated at early ages during hydration and form secondary C-S-H gel (also referred as tobermorite gel). This gel is less dense and has more volume than primary C-S-H gel. Therefore it fills all the pores inside concrete and makes the concrete more impermeable. Therefore it reduces the risk of chloride and sulfate induced deterioration.

Slag has been widely used as successful replacement material for ordinary Portland Cement (OPC) in making durable concrete for improving some properties of concrete in marine environment and for achieving environmental and economical benefits since the beginning of 20<sup>th</sup> centuries. Slag is a by product of steel production. Its major chemical compounds are CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, MgO, TiO<sub>2</sub> and MnO and hence similar to OPC, slag has the cementitious property. Due to its very high fineness, it can effectively fill the pores of the concrete which are very much helpful for reducing the permeability of concrete. Impermeable concrete restricts the penetration of sea water inside the concrete and therefore increases the durability of concrete in sea water environments.

Table 2  
Composition of Artificial Sea Water [29]

Salt	Chemical formula	Amount (gm/liter)	% of total salt	Remarks
Sodium chloride	NaCl	27.21	77.74	These amounts of salts were dissolved in plain water to prepare 1000 gm of Sea water of 1N Concentration
Magnesium chloride	MgCl <sub>2</sub>	3.81	10.89	
Magnesium sulfate	MgSO <sub>4</sub>	1.66	4.74	
Calcium sulfate	CaSO <sub>4</sub>	1.26	3.60	
Potassium sulfate	K <sub>2</sub> SO <sub>4</sub>	0.86	2.46	
Calcium carbonate	CaCO <sub>3</sub>	0.12	0.34	
Magnesium bromide	MgBr <sub>2</sub>	0.08	0.23	
Total		35.00	100.00	

Slag cement has been used in different concrete projects of the United States of America for the last several decades. Besides, earlier usage of slag cement in Europe and elsewhere demonstrate the long term performance of slag concrete in many ways. Use of slag has also been noticeably increasing for the last several years due to its characteristic properties such as improved workability, restrained heat of hydration, easier

finishability, higher compressive strength, lower permeability and superior resistance to alkali silica reaction due to penetration of chloride ions and sulfate ions [22]. It has been observed that slag can be effectively used to reduce the pore sizes and cumulative pore volume considerably leading to more durable and impermeable concrete [23]. Industrial slag, in general, has the potential to replace cement in high percentage because of its in built cementitious property [24]. Although the strength development is remarkably reduced at early ages of curing due to having low initial rate of hydration of slag, the structural benefit of low heat of hydration of slag in decreasing the thermal cracking of mass concrete is significant. The risk of thermal cracking in slag concrete is seen to be lower than ordinary Portland cement. In Europe, the production of 1 ton OPC generates about 1.2 ton CO<sub>2</sub> while the production of 1 ton slag generates only 0.45 ton of CO<sub>2</sub> [25]. In addition, concrete made with slag has a lower content of chromium, which is responsible for skin irritation of workers handling concrete materials without any skin protection [26].

Relevant literature reveals that addition of slag as a partial replacement of cement in making concrete reduces the permeability of concrete, which in terms may resist the penetration of harmful salt ions within the concrete structure. The relevant studies indicate that the percentage of cement replacement with slag and their relative proportion for making concrete in such environment is very important. Optimum use of slag must be ensured for the desired strength as well as durability requirement of the structural concrete. The progress of cement hydration reaction and the rate of penetration of different salt ions in tropical condition are reported to be much faster than those of cold countries like Europe and North America [27]. Thus, it is vital to understand the process and mechanism of chloride and sulfate induced deterioration of structural concrete in tropical climatic countries like Bangladesh. Incidences of maximum damages are reported to occur in splash/tidal zone. This is due to the active presence of all process of deterioration, which may be physical, mechanical and chemical in nature. In this regard, proper research is required to investigate the performance of slag concrete made with various replacement of cement content in splash/tidal zone condition. This paper investigates the strength behavior of slag concrete in sea water environment. The use of slag as partial replacement of cement in concrete exposed to artificial sea water environment has been studied over a year particularly from the development of the compressive strength point of view. Various slag cement ratios (100:0, 85:15, 70:30 and 55:45) as well as sea water of different concentration (1N, 3N and 5N) have been used to get the idea for optimum mix ratio of slag cement in making concrete in such location. The test data may provide useful information regarding the use of slag concrete in sea water environment which may also help to make proper management of slag thereby resulting environmental benefit in a society.

## 2. Experimental Program

The experimental work was carried out to study the different aspects of deterioration of slag concrete by using both plain water and sea water of different concentration over a period of 365 days. The variable parameters studied and the materials involved were as follows:

### 2.1 Materials

(a) *Cement*: Ordinary Portland Cement (OPC) ASTM Type-1, conforming to ASTM C-150 was used as binding material. Its physical properties and chemical compositions are given in Table 3.

(b) *Slag*: Electric arc furnace slag was used in this investigation. Chemical compositions of the used slag are given in Table 4.

(c) *Aggregate*: Locally available natural sand passing through 4.75 mm sieve and retained on 0.075 mm sieve was used as fine aggregate. The coarse aggregate was crushed stone with a maximum nominal size of 12.5 mm. The grading of the aggregates and its physical properties are given in Table 5.

Table 3  
Physical properties and Chemical composition of OPC

Sl. No	Characteristics	Value
1.	Blaine's Specific surface (cm <sup>2</sup> /gm)	2900
2.	Normal Consistency	26 %
3.	Soundness by Le Chatelier's Test (mm)	4.5
4.	Specific gravity	3.15
5.	Setting Time	
	(a) Initial (min.)	70
	(b) Final (min)	175
6.	Compressive Strength	
	(a) 3 days (MPa)	15.2
	(b) 7 days (MPa)	20.2
	(c) 28 days (MPa)	30.4
7.	Calcium Oxide (CaO)	64%
8.	Silicon Dioxide (SiO <sub>2</sub> )	21%
9.	Aluminum Oxide (Al <sub>2</sub> O <sub>3</sub> )	6%
10.	Feric Oxide (Fe <sub>2</sub> O <sub>3</sub> )	3.5%
11.	Magnesium Oxide (MgO)	1.2%
12.	Sulfer Trioxide (SO <sub>3</sub> )	2.5%
13.	Loss on ignition	1.2%
14.	Insoluble matter	0.6%

## 2.2 Variables

(a) *Curing solution*: Plain water (PW) as well as artificially made sea water (SW) of concentration 1N, 3N and 5N were used for curing the test specimens. 1N sea water means normal sea water made by mixing tap water with exact amount and proportion of principal salts found in natural sea water (see Table 2. Thus 5N will have salt concentration enhanced to 5 times as for normal sea water. The enhanced concentration was used to obtain accelerated effects.

Table 4  
Chemical Composition of slag

Sl. No	Constituent	Percentage
1.	Calcium Oxide (CaO)	43%
2.	Silicon Dioxide (SiO <sub>2</sub> )	36%
3.	Aluminum Oxide (Al <sub>2</sub> O <sub>3</sub> )	14%
4.	Feric Oxide (Fe <sub>2</sub> O <sub>3</sub> )	1%
5.	Magnesium Oxide (MgO)	4%
6.	Sulfer Trioxide (SO <sub>3</sub> )	0.5%
7.	Free lime	1.5%

(b) *Concrete quality*: Four different grades of slag concrete with cement slag ratios 100:0, 85:15, 70:30 and 55:45 were used. Cement slag ratio 100:0 i.e. OPC concrete was cast for comparing its properties with that of slag concrete.

(c) *Exposure period*: Test specimens were tested periodically after the specified curing periods of 30, 90, 180 and 365 days in plain water, 1N, 3N and 5N sea water environments.

(d) *Size of specimens*: 100 mm x 100 mm x 100 mm cube specimens were prepared following ASTM standard procedure.

(e) *Curing Environment*: A total of 300 mortar specimens were cast in the laboratory. After casting, the specimens were kept at 27°C temperature and 90% relative humidity for 24 hours. After demoulding, all the specimens were cured in plain water for 30 days at room temperature. After 30 days plain water curing, the specimens were submerged in tanks containing PW, 1N, 3N and 5N sea water for different exposure periods.

Table 5  
Grading and Physical Properties of Fine and Coarse Aggregate

Properties	Coarse Aggregate	Fine Aggregate
Grading of Aggregates		
Sieve Size (mm)	Cumulative % Passing	
25.0	100	--
12.5	100	--
9.5	45	--
4.75	0	100.0
2.36	--	94.0
1.18	--	78.5
0.6	--	55.5
0.3	--	13.0
0.15	--	2.5
Physical Properties of Aggregates		
Specific Gravity	2.67	2.59
Unit Weight	1635 kg/m <sup>3</sup>	1540 kg/m <sup>3</sup>
Fineness Modulus	6.45	2.57
Absorption Capacity	0.8 %	1.2 %

### 3. Results and discussion

The results of the test specimens have been critically analyzed and presented both in graphical and tabular forms. Figs. 2 to 6 present the experimental results of compressive strength of slag concrete for different mix proportions of cement slag, curing environments and curing periods. The strength values corresponding to '0' day curing period mean the strength of the specimens after 30 days PW curing. These figures clearly demonstrate that the concrete specimens with cement slag proportions 70:30 gives lower strength deterioration for longer curing periods. In case of plain water curing, OPC concrete shows higher strength at initial ages than that for slag concrete. But for relatively longer curing periods, the differences between the results are seen to be decreased. In case of plain water curing and for OPC concrete, the compressive strength for 1 month exposure period is 22.7 MPa whereas the corresponding values are 20.7 MPa, 20.6 MPa and 19.8 MPa for slag concrete of cement slag mix ratio of 85:15, 70:30 and 55:45 respectively. But after 12 months curing, compressive strength is 34 MPa for



OPC concrete whereas 32.6 MPa, 33.2 MPa and 32.4 MPa for slag concrete of cement slag mix ratio of 85:15, 70:30 and 55:45 respectively. This is due to slow hydration rate of slag and for this reason, the gain in strength at early age is comparatively lower although after longer curing period, slag concrete attains almost the same strength as that of OPC concrete. Test results also show that compressive strength of both OPC and slag concrete is reduced when it is exposed to sea water as compared to plain water curing. Slag concrete of cement slag mix ratio 70:30 cured under plain water for 6 months shows a compressive strength 30.1 MPa, whereas the corresponding values are 28.2 MPa, 27.9 MPa and 24.7 MPa for the same concrete and same curing period but exposed to sea water of 1N, 3N and 5N concentration. Thus it is clear that compressive strength is reduced with the increase in sea water concentrations although the nature of variation is not proportional.

Effect of seawater on the compressive strength of slag concrete can also be explained in terms of relative strength of concrete for different mix proportions of cement and slag, curing environment and curing periods. Figs. 7 to 11 show the relationship between relative strength and exposure periods for different curing environment. In case of 1 month curing (Ref. Table 6) reduction of strength with respect to plain water curing is 7%, 10% and 20% for OPC concrete cured in seawater of 1N, 3N and 5N concentration, whereas the corresponding values are 10%, 17% and 25% for slag concrete of cement slag mix ratio 70:30. But after 12 months curing, the strength reduction values are 11%, 14% and 21% for OPC concrete and 9%, 11% and 18% for slag concrete of cement slag mix ratio 70:30. However the loss in compressive strength when compared with 12 months compressive strength of plain water cured concrete are observed to lie in the range of 11% to 21% for OPC concrete, 14% to 22% for 85:15, 9% to 18% for 70:30 and 11% to 22% for 55:45 slag concrete when exposed to seawater of different concentrations, Possible cause for strength reduction is the formation of expansive as well as leachable compounds when concrete specimens are cured in seawater. Sea water enters into concrete and reacts with hydrated product of cement and slag forming ettringite or frields salt. Due to these expansive materials, microcracks are developed inside concrete and the bond between hydrated product and aggregate particles become weak. The concrete gradually becomes porous due to leaching action of the newly formed compounds. Thus, the concrete is deteriorated and loss in compressive strength of concrete is occurs.

Figs. 12 to 16 show the relationship between ultrasonic pulse velocity of slag concrete and exposure periods for different curing environment. For curing period of 1 month, from Table 7 UPV value for OPC concrete is 3790 m/s in plain water environment, whereas corresponding values are 3680 m/s, 3660 m/s and 3580 m/s for slag concretes of cement slag mix ratio 85:15, 70:30 and 55:45. But after 12 months curing these values are 4510 m/s for OPC concrete, 4450 m/s for 85:15, 4470 m/s for 70:30 and 4460 m/s for 55:45 slag concrete. At initial ages of curing, the differences between these values are higher but during later ages of curing the differences become smaller. This is due to the fact that hydration rate for OPC concrete is higher than that of slag concrete. Figs. 12 to 15 show the variation of UPV values for the specimens cured in seawater of different concentration for various exposure periods. After 1 month curing, the UPV value is 3390 m/s for OPC concrete cured in sea water of 5N concentration, whereas this value for slag concrete of cement slag mix ratio 70:30 is 3210 m/s for similar curing condition. But for longer exposure periods, it is observed that slag concrete has higher UPV values than OPC concrete. After 12 months exposure periods, UPV value for OPC concrete cured in seawater of 5N concentration is 3860 m/s, whereas the corresponding value for 70:30 mix is 3920 m/s for same curing condition. Also after 1 month curing, reduction of UPV

values compared with plain water cured specimen is 400 m/s for OPC concrete, 460 m/s for 85:15, 450 m/s for 70:30 and 470 m/s for 55:45 slag concrete when exposed to sea water of concentration 5N, whereas after 12 months curing these values are 650 m/s for OPC concrete, 580 m/s for 85:15, 550 m/s for 70:30 and 590 m/s for 55:45 slag concrete for the identical exposure condition. This is due to slow hydration of slag in slag concrete. At relatively longer curing periods, complete hydration of slag takes place and produces an impermeable concrete, which prevents the easy penetration of seawater into the concrete and thereby resulting in lower rate of deterioration.

From all the above discussion it is clear that slag concrete shows relatively higher resistance against strength deterioration and reduction of UPV values. Among all concrete, slag concrete cast with cement slag mix ratio 70:30 shows lowest strength reduction. The resistance against strength deterioration of slag concrete is due to higher degree of fineness of slag, which after hydration blocks the pores inside the concrete thereby reducing its permeability. As a result, entrance of sea water in concrete is restricted and the amount of salt ion penetration is thereby greatly reduced. Thus the rate of deterioration is seen to be decreased in slag concrete.

#### **4. Conclusion**

Based on the limited number of test variables and exposure conditions / periods stated above, the following conclusions can be drawn. The study may provide some necessary information related to the use of slag concretes for the construction of marine onshore / offshore reinforced concrete structures:

- (1) The development of compressive strength for slag concrete is not significant at the early age of curing. The gain in strength occurs at relatively rapid rate at later ages of curing.
- (2) Mix proportion of slag with cement has a significant effect on strength development of slag concrete. Among the mix proportions studied, the 70:30 mix slag concrete shows higher compressive strength.
- (3) Slag concrete shows better resistance against strength deterioration. Among all the concrete, slag concrete of cement slag mix ratio 70:30 shows the least strength deterioration in seawater environments.
- (4) Concrete made with cement slag mix ratio 70:30 shows least deterioration of UPV values for any curing solution which indicates the presence of micro cracks inside 70:30 slag concrete is relatively lower.
- (5) Slag concrete made from blending of slag with cement in different proportion can reduce the strength deterioration and improve durability characteristics of concrete in sea water. High fineness of slag which after hydration greatly reduces the permeability of concrete limits the penetration of sea salt ions into it.
- (6) Among the slag concretes, concrete of cement slag mix ratio 70:30 is found to be most effective in resisting the adverse effect of marine environment.

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