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Research Article

DISASTER IN CONCRETE DUE TO CHEMICAL INGRESS

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ABSTRACT

The disaster in concrete is a natural phenomenon which is subjected to frequent ingress of chemicals as sulphate, chloride, nitrates, fluorides and also subjected to the atmospheric effects as freezing and thawing. The effects encountered due to these processes results in the decrease of the durability of concrete. The strength parameters are also affected. The continuous ingress of chemicals makes the concrete highly porous which ultimately reflect surface dampness. The chemicals react with the concrete constitutions and make it less resistant to aggressive environment resulting in deterioration of concrete. Therefore, the concrete is to be enhanced to prevent the ingress of the chemicals with the help of pozzolanic materials to increase the durability of concrete. Laboratory test on chloride ingress into concrete subjected to airborne salt is carried out by means of the original wind tunnel. The result shows that surface chloride is dependent of intensity of airborne salt. The dependency of surface chloride content on water cement ratio is not clear. Mean surface chloride determined from short-term exposure test underestimates long-term chloride ingress into concrete. The carbonation depth was measured by taking example with different case studies. The carbonation depth measurement was summarised in tabular form and result was analysed.

Keywords: *Ingress, Freezing & Thawing, Pozzolanic, Aggressive Environment, Wind Tunel*

INTRODUCTION

The chloride, sulphate& aluminates constitute a major risk of chemical aggression of concrete during disaster. Recent studies have shown that the ingress of these chemicals are the major cause for the reduction of the service life of the structures (JSCE, 2002). The internal expansion reaction due to ingress of some chemicals as alkali resulting chemical reaction as alkali-aggregate reaction occurs during the disaster which results as a cracking visibility on the concrete surface identified by visual inspection which affect the function ability of structures.

Chloride ingress into concrete is known as one of the most important factors affecting durability of concrete structures since it causes corrosion of steel reinforcement embedded in concrete causes of chlorides in actual concrete structures are splash and tidal action of sea water, airborne salt from the sea, dicing agent and initially induced chloride with sea sand (EFNARC, 1996; Kenji, 2009). In this paper, airborne salt which dominates service life of coastal concrete structures is focused. According to the Standard Specification for Concrete Structures by JSCE, the time when chloride content at the reinforcing bar portion in concrete reaches the designated threshold value is defined as one of the limit states of structural durability. The time-dependent chloride content in concrete is calculated by Fick's diffusion equation, in which empirically determined surface chloride content is used as a boundary condition, depending on distance from the shore line.

The reaction of alkali –aggregate is the chemical reaction that develop among certain types of mineral aggregates, the alkali ions and hydroxyl ion (OH) Present in the interstitial cement paste (Licentiate Thesis, 2000). This reaction leads to creation of hygroscopic silica gel.

These reactions are highly expansive leading to development of internal stresses and consequent cracking of concrete and often accomplished by efflorescence and exudations on concrete surface.

Purpose

The main purpose of this paper is to manufacture concrete which is highly resistant towards chemical attack such as ingress of chlorine, sulphate attack and carbonation effect and can prevent ingress of chemicals during disaster period (AITES World Tunnel Congress, 2005). The modelling of different cross section of concrete towards the chemical attack and then selecting the most chemical resistant cross section is also the purpose of this paper.

MATERIALS AND METHODS

Experimental Methodology

The chloride ingress is measured by non-destructive technique which are based upon three methods: Electrical resistivity, Ion selective electrode (ISE) and optical fibre sensor.

Specimen Concrete specimens whose size is 100 x 100 x 150 mm were used. Two types of concrete mix whose water cement ratio is 40% and 60% were used. Specimens were cured in water for 28 days. However, concrete strength was not measured. After curing, five surfaces of each specimen except one exposed surface were coated with tar epoxy**.**

Experimental Method

Wind Tunnel

The wind tunnel is used to determine the chloride ingress in the coastal environment involving airborne salt simulation. The size of the cross section inside of the wind tunnel is 1 m x 1 m. The length of wind path is about 12 m in one round. Particles of salt water are produced by putting fine air bubbles into the salt water unit and blown by the fan. Concrete specimens are set in both the first and the second floor and exposed to wind involving airborne salt. Wind velocity and amount of airborne salt at installation position of each specimen in the wind tunnel were measured prior to the exposure test. Wind velocity was measured by a portable wind velocity meter. The measured wind velocity in the tunnel was 1.5 m/s in average. The amount of airborne salt at each specimen's position was measured by a gauze specimen whose size is 100 mm x 100 mm. Gauze specimens are exposed at the testing position for four hours to catch airborne salt.

Measurement data on initial chloride content in concrete before the exposure, the average chloride content on 12days were used as initial chloride content.

Hence, adjusted chloride ingress into concrete at each exposure time was calculated by drawing the initial value from the measured absolute chloride content. Chloride content in concrete during exposure increased with increasing of the intensity of airborne salt to sure time at every portion of all the specimens.

Increasing of chloride content near the surface is greater than those in the deeper portion.

It is regarded that chloride ingress into concrete is affected by the intensity of airborne salt. Comparing specimens made of same concrete mixture, chloride ingress is accelerated by the intensity of airborne salt to which the specimen is continuously exposed. Part of the airborne salt which reached the surface of concrete was caught and gradually penetrated into concrete by diffusion mechanism. It is supposed that the amount of airborne salt caught by concrete surface is dependent of the intensity of airborne salt.

Measurement of Chloride Content in Concrete: To measure chloride content in concrete, samples of concrete powder were taken from the specimen by drill at 100 mm, 200 mm, and 400 mm from the exposed surface. Chloride content in concrete was measured by a chloride ion meter. The procedure for measurement is discussed below Water- and acid-soluble chloride concentrations in concrete made with different cements are shown in Figure below. Significant difference of chloride concentration profile is observed for SCB and AL compared with the others. In the case of AL, a higher chloride concentration is observed at the surface region of the specimen, but it quickly drops with distance inside the specimen. For SCB, the peak chloride concentration is observed near the surface region and it drops with distance inside the specimens. The chloride level at 75 mm depth, however, is higher for SCB compared with the AL. For OPC, HES, and MH, the chloride distribution pattern is almost same. For these cases, a lower chloride concentration is observed at the surface region and rises to a constant value at the inner region. For OPC, HES, and MH, the chloride concentration at a cover depth of 75 mm is 10 times higher than the chloride concentration at a cover depth of75 mm for SCB and AL. Based on the micro structural investigation, 5 it was found that the outer region became denser compared with the inner region for SCB and AL, and the improvement was significant for AL. The data strongly suggest that the denser microstructure of SCB and AL, as well as the improvement of microstructure at the outer region of the specimen with the on-going exposure in marine environment, reduces chloride ingress in concrete (EFNARC, 1996)**.**

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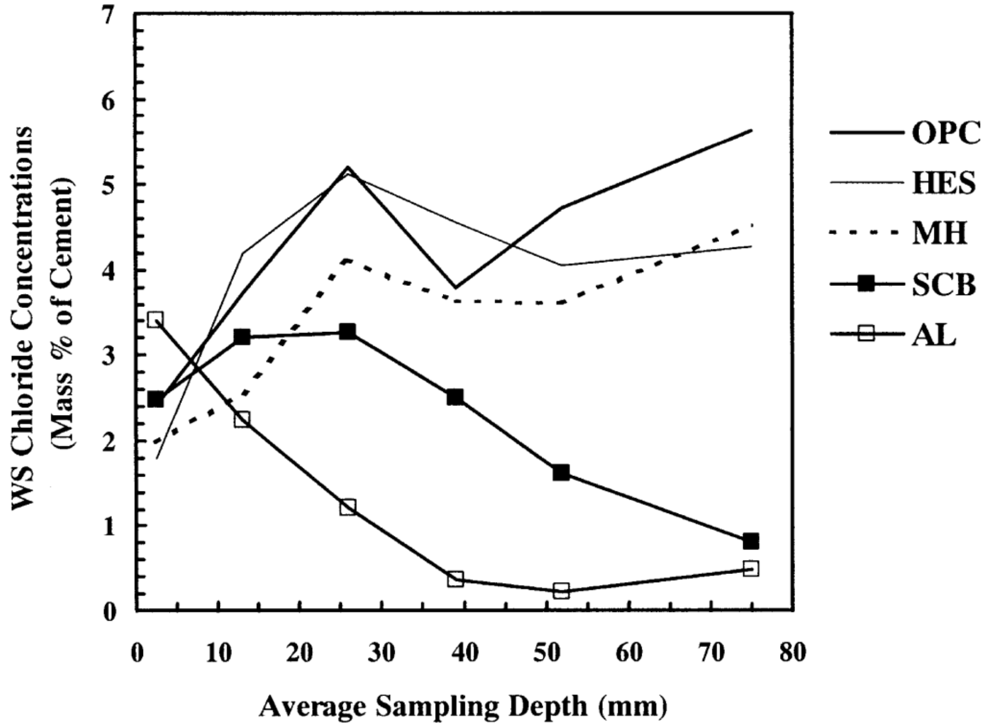
A similar result was also observed for SCB after 15 years of marine tidal exposure.1 These results indicate that use of SCB or AL is very effective limiting the chloride ingress in concrete. AL showed reduction in compressive strength.



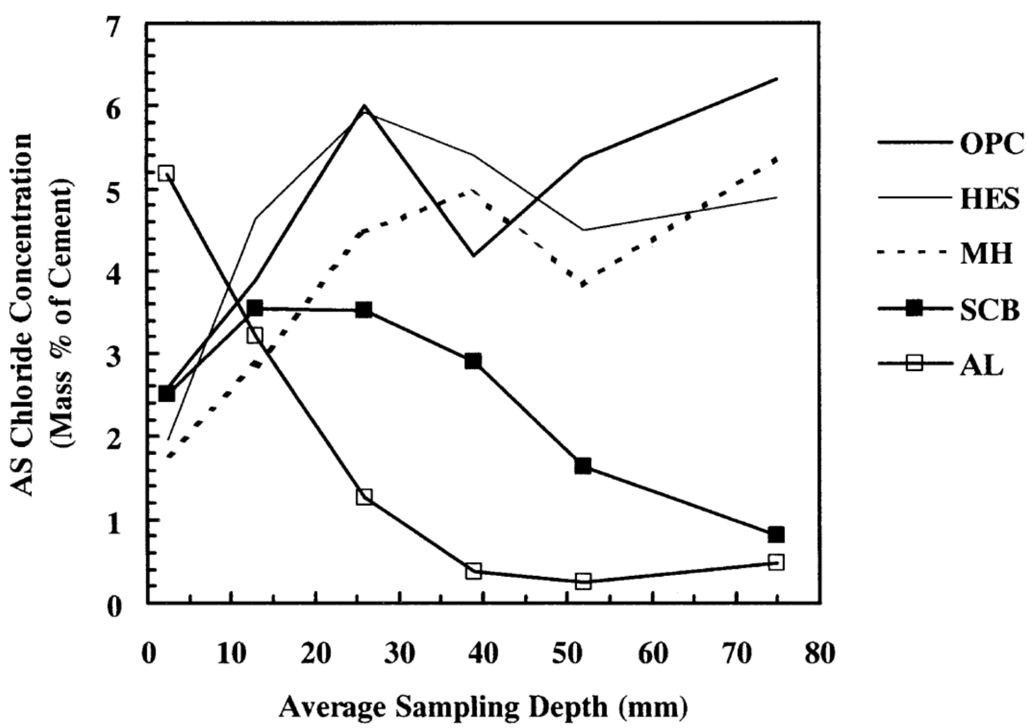


Figure1: The chloride concentration variation diagram in different types of concrete.

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Half-Cell Potential, Concrete Resistance and Microcell Corrosion Test.
Half-cell potential (versus Ag/AgCl), concrete resistance, and microcell corrosion current density data are shown in the following Figures over the steel bars located at 20, 40, and 70 mm of activity, while AL lies between. A quantitative evaluation of the passive condition of the steel bar was made. The passivity grades were as follows: SCB was Grade 4; AL was Grade 3; and OPC, HES, and MH were Grade 1, irrespective of the cover concrete depth (Erik Nordstrom, 2000). A higher grade of passivity for the steel bars embedded in SCB indicates less corrosion activity and this was confirmed by visual observation.

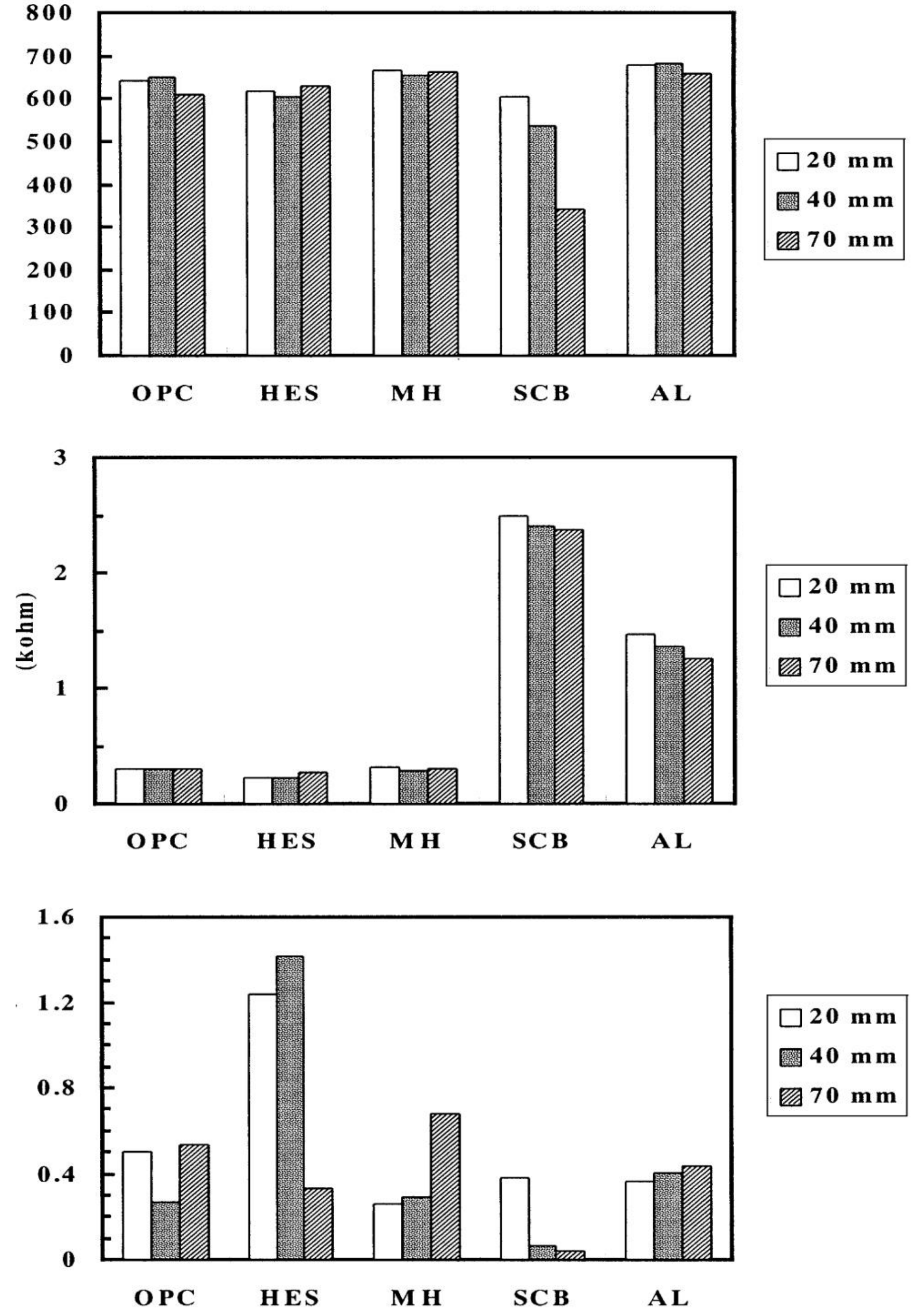

Figure 2: The bar chart diagram representing passivity of steel.

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Detailed depth profile of sulphate ingress into the concrete is measured with laser introduced breakdown spectroscopy

***The Carbonation Depth Measurement Test*:** This test is carried out to establish the extent of carbonation in concrete. The concrete surface is treated with a solution of phenolphthalein in diluted alcohol. If ca (OH)2 is unaffected by CO2, then the colour turns out to be pink. If the concrete is carbonated, then it will remain uncoloured. To study the carbonation effect, the experiment was performed on two test block of concrete. One concrete block was M20 grade taken from age group of 2, 5, 10*50 years old and other concrete block was M40 also taken of same age group. The depth of Carbonation was noted in each case with different percentage of relative humidity. It was noted that highest rate of carbonation occurs at a rate of relative humidity of between 50-70 percent. The depth of carbonation by performing the experiment was noted as below

Age-Years	Depth of Carbonation: M20	Depth of Carbonation: M40
2	4.8	.5
5	7.8	.9
10	11.5	1.2
50	24.6	3.8

Mechanical Strength Test of Concrete during Disaster

Mechanical Strength of Concrete with Fly Ash Content:

Mechanical properties of High-Strength Concrete (HSC) can be divided in two groups as short-term mechanical properties and long-term mechanical properties. A discussion on short-term mechanical properties of concrete which includes, compressive strength, stress-strain behaviour, elastic modulus, Poisson’s ratio, tensile strength and modulus of rupture, is presented here **[5].** The equations and formulations that are used for normal strength concrete (NSC) cannot always be extended to include HSC, and need to be revisited. Important parameters that affect these properties and mathematical formulations that represent the behaviour of HSC more appropriately are summarized here.

An experimental study was conducted to know the influence of chemical composition in the strength deterioration of concrete during disaster period. In the first series of the test program, 6 concretes were cast by varying fly ash-binder ratios and water-binder ratios. The fly ash-binder ratios used were 0.20, 0.35 and 0.50 and water-binder ratios were 0.40 and 0.50. In second series 6 concretes of similar composition were cast, the only difference being that fine sand was used in place of fly ash in order to compensate the effect of fineness of fly ash on strength development of concrete. The fine sand was ground to approximately obtain the same specific surface area as that of fly ash. In third series of tests another fly ash of different chemical composition was used to repeat the strength tests. The compressive strengths were obtained after 3, 7, 28, 90 and 180 days of standard moist curing. It was found that contribution of chemical composition to strength increased with age and with increase in fly ash-binder ratio and it ranged from 12% to46% of total strength.

The concrete cube prepared with different fly-ash binder ratio and the concrete prepared without fly ash binder were cured properly. After that these concrete cubes were subjected to chloride ingress by the diffusion process in a wind tunnel apparatus. The chlorine ingress exposure was kept for 10-12 hours. The Specimen were taken out of wind tunnel apparatus and Compressive strength was tested in compressive testing machine. The mechanical strength was also tested. During testing, it was observed that the concrete cube having higher value of Fly ash binder ratio showed appreciable strength in comparison to other concrete cube even after ingress of chloride content upto 10-12 hours’ exposure time. The strength of this particular concrete cube also increased appreciably with increase in the curing period. The result data was recorded by taking Compressive strength observation of three concrete cubes of M20, M25*M35 Made with OPC, HES, SCB*AL cement, The Compressive Strength of these grades of concrete was also noted by chlorine exposure of 10-12 hours. The curing period was kept 14 days *28 days.

Grade Strength, N/mm2	M20				M25				M35			
	SCB	HES	OPC	AL	SCB	HES	OPC	AL	SCB	HES	OPC	AL
Compressive Strength OF 14 days curing												
Compressive Strength of 28 days curing	18.5	17	17.8	16.9	24.8	22.7	22.8	23	33,5	31	31.5	32.6
Compressive strength of 14 days curing *Exposure of chlorine for10-12hours.												
The 28 days compressive strength after exposure of chlorine of10-12 hours	16.75	11	12.5	15	22.5	18	17	21	31	25	24	30

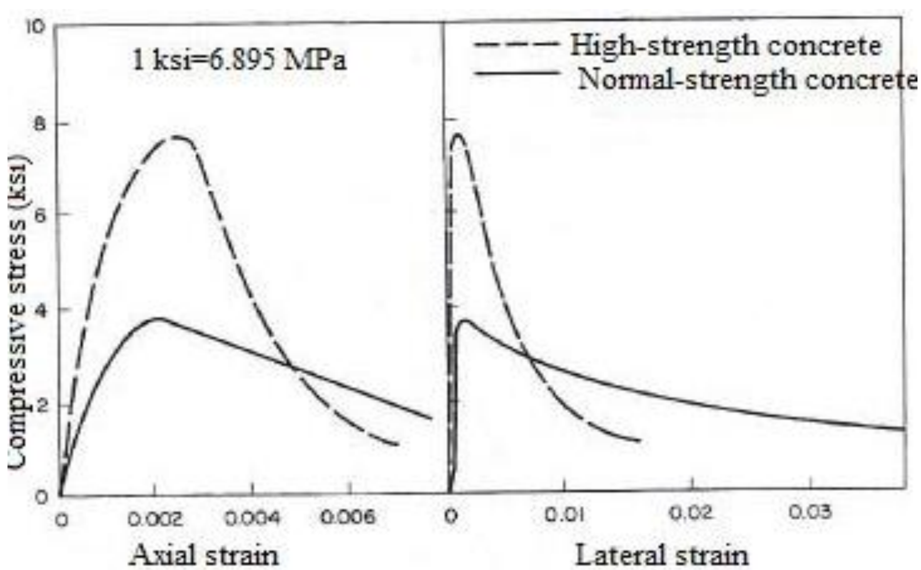

Figure 3

The chloride resistance, Carbonation resistance and Sulphate resistance of concrete depends also upon curing period. The concrete sample properly cured gains sufficient strength and has appreciable compressive strength against chemical changes during disaster as clear from graph below by conducting curing test of above specified grade of concrete in different time interval.

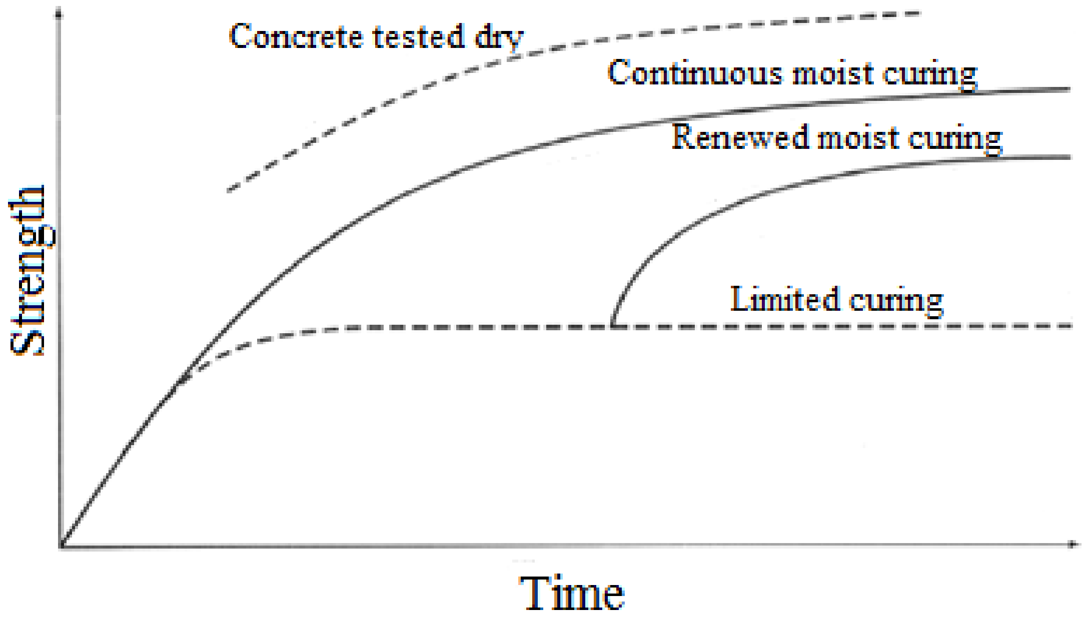

Figure 4

From observing table, it is clear that the strength of concrete made with slag cement does not go very low even after ingress of chlorine upto 10-12 hours. However, other concrete shows very poor results due to ingress of chlorine.

Mechanical Strength Test on Sample Concrete Subjected to Highly Disaster Prone Area: A detailed investigation on 30-year-old concrete specimens of 150 and 300 mm in diameter and height, respectively, made with ordinary portland cement (OPC), high early-strength Portland cement (HES), moderate heat portland cement (MH), Type B slag cement (SCB), and alumina cement (AL) was carried out. Three steel bars were embedded at cover depths of 20, 40, and 70 mm.

Carbonation depth, water- and acid-soluble chloride contents, and electrochemical and physical evaluation of corrosion were evaluated. Chloride ingress in concrete was lower for slag and alumina cements compared with the others. More corrosion over the steel bars, however, was found for alumina cement due to the porous steel concrete interface.

The surface condition of the steel bars embedded in concrete made with slag cements remains the same as the initially polished condition. Using slag cement is concluded as one of the best choices to improve the long-term durability.

The deterioration process of reinforced concrete structures due to chemical–physical phenomena can be profitably analysed taking the data and result of above mentioned experiment by means of model-based simulations, performed by using a mathematical/numerical approach. In this work both the model of humidity, pollutant and temperature diffusion, and the mechanical damage approach have been applied to some real cases with the aim of establishing a possible develop-line for the analysis of degradation that can be applied to real engineering structures. The model simulation was prepared for the compressive /Mechanical strength versus depth of chloride ingress, depth of carbonate ingress*the depth of Sulphate ingress. This model simulation helps to determine the compressive strength as well as mechanical strength for any degree of chlorine ingress, carbonate ingress sulphate ingress. And the intend is the evaluation of the structural safety and the prediction of the expected service life of reinforced concrete structures.

The Tensile Strength of Concrete

Tensile strength of concrete is measured by direct and indirect tensile tests. Direct tensile tests, which include testing HSC specimen under pure tension, are difficult to perform due to testing limitations. Indirect tests include flexure and split-cylinder tests, and are used popularly to measure tensile strength of concrete.

Modulus of Rupture

Modulus of rupture is evaluated in flexure test as a function of compressive strength. General expression for modulus of rupture is given as:

Where, is a constant that takes a value between 7.5 and 12 if is expressed in psi, and between 0.62 to 0.99 if is expressed in MPa, respectively (ACI, 2010). These expressions provide good agreement with experimental data upto strength of 100 MPa, but often underestimate the values for higher strength. c r f r f

Splitting Tensile Strength

ACI 363R-10 (ACI, 2010) reports a study by Dewar (1964) that claims that for lower strength concrete, tensile strength may go upto 10% of compressive strength; however, for higher strength it reduces to 5%. Expressions used for calculation of splitting tensile strength are: 5

RESULTS AND DISCUSSION

Result Analysis

The result analysis of concrete carbonation from the observation noted in the table above clears that carbonation depth decreases with increase in the grade of concrete. Also the rate of carbonation will be slower in case of stronger concrete with the reason that stronger concrete is much denser with lower W/C ratio.

The result analysis of ingress of chlorine was thoroughly studied and conclusions were noted as below.

(1) Time-dependent chloride profile in concrete subjected to airborne salt can be obtained by the developed wind tunnel test.

(2) The obtained surface chloride content of concrete is dependent of the intensity of airborne salt.

(3) The obtained diffusion coefficient of concrete with low water cement ratio is relatively smaller than that with high water cement ratio.

(4) Chloride ingress analysis based on constant diffusion coefficient over estimates long term chloride content in concrete.

(5) Chloride ingress analysis based on time-dependent diffusion coefficient can estimate long term chloride profiles better than constant diffusion coefficient.

The structural modelling prepared for unit thermal temperature variation shows that circular cross-section is more influenced by internal reaction, followed by diamond section and finally the rectangular section as least.

Conclusion

The main conclusion drawn from this paper is that the concrete prepared to face the disaster effect by preventing the chemical ingress should be impermeable, void less. The use of pozzolona by virtue of pozzolanic reaction makes the concrete impermeable. The high alumina cement is highly resistant to the action of sulphate. Thus, use of high alumina cement together with partial replacement with pozzolana makes the concrete highly resistant.

The conclusion drawn on the basis of results observation on model cross section reveals the following main conclusions were drawn based on the investigation on concrete specimens exposed to the marine submerged exposure for 30 years:

1. Concretes made with slag and alumina cements show less chloride ingress and reduced oxygen permeability compared with the OPC, MH, and HES cements of the same *w*/*c*;
2. Steel bars in concrete made with slag cements show a higher degree of passivity. The surface condition of the steelbars for slag cements remains as in the initially polished condition before embedded in concrete;
3. For AL, relatively more corrosion over the steel bars is found even for less chloride ingress and also less oxygen permeability. This was attributed to a porous steel-concrete interface; and
4. Use of slag cement is found to be the best choice to improve the long-term durability of materials the fact that rectangular cross section of concrete should be recommended in highly disaster prone area where there are more chances of chemical ingress into concrete.

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