

Reliability Assessment of Flyash Blended Cement Concrete with Organic Inhibitor

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Abstract - Sodium chloride in the water used for making concrete leads to corrosion of reinforcement bars Reinforced Cement Concrete works. In course of time, corrosion continues to reduce the steel reinforcement and weakens the reinforcement .corrosion of steel bars in concrete is a serious problem from both the economic and structural integrity standpoint. Corrosion in reinforced concrete structures can be reduced by bringing down the chloride level in the water used for making. To study the strength, micro structural and corrosion resistance characteristics of fly ash blended cement concrete with 3% addition of diethanolomine as inhibitor, experimentally and evaluate its performance with that of fly ash blended cement concrete without inhibitor.

Reinforcement concrete is the common materials used in most parts of the construction world which needs less maintenance when compared to steel structures. But the reliability of Reinforced Concrete structures mainly depends on the steel embedded in concrete. The pH value of the pore water inside the concrete mix and the passive layer around the steel surface determines the corrosion rate of steel. In this work the effect of organic inhibitor – diethanolomine in concrete is studied. The inhibitor added in concrete with correct proportion and proper curing makes a substantial improvement in enhancing the protection of embedded reinforcing steel in concrete from corrosive agents. The various mix proportion used for test are 10%, 20%, 30% and 40% replacement of cement with fly ash. The reliability analysis can be used to measure the degree of conservation associated with the deterministic analysis & that repair intervention of deteriorating structures can safely be delayed by carrying out a reliability analysis. The results were analyses in the reliability analysis.

The reliability index of the beam is calculated and a graph plotted. From the graph the intervention time of the concrete specimens is studied.

Keywords: Flyash, Corrosion, Diethanolomine, Reliability Index.

1. INTRODUCTION

1.1 General

Corrosion is a well – understood electrochemical phenomenon that takes place when the passivity is destroyed due to the carbonation of concrete in contact with steel, or penetration of soluble chlorides right up to the reinforcement due to permeability or cracks. The strong alkaline nature (pH of about 13) of Ca (OH) 2 prevents the corrosion of steel reinforcement by the formation of a thin protective film on the metal surface.

1.2 Definition of Corrosion

Corrosion can be defined as deterioration or destruction of metals and alloys because of its reaction with the environments.

1.3 Causes of Corrosion

Following are the causes of corrosion in concrete structures

- Use of poor quality materials
- Use of poor quality of concrete mix.
- Inadequate cover thickness to reinforcement in the concrete.
- Use of more chloride-contaminated water to the concrete.
- Porosity of concrete at the time of casting.
- Type of environment such as marine and industrial environments.

1.4 Types of Corrosion

1.4.1 Uniform Corrosion

Steel undergoes corrosion damage uniformly over the entire area when sufficient quantities of moisture are present Aggressive environments like marine environment promote severe corrosion.

1.4.2 Pitting Corrosion

In the case of pitting corrosion there is a preferential attack of a particular area of surface. The exposed metal gives up electrons easily and the reaction initiates tiny pits with localized chemistry supporting rapid attack. Control can be ensured by

- Selecting a resistant material.
- Ensuring a high enough flow velocity of fluids in contact with the material or frequent washing.
- Control of the chemistry of fluids and use of inhibitors.
- Use of a protective coating.
- Maintaining the material's own protective film.

1.4.3 Crevice Corrosion

Crevice or contact corrosion occurs in place where metal is in contact with non-metallic materials and also on valve seals, welded joints, threaded connections. Differential aeration cells produce the crevice corrosion. The potential for crevice corrosion can be reduced by

- Avoiding sharp corners and designing out stagnant areas
- Use of sealants
- Use of welds instead of bolts or rivets
- Selection of resistant materials

1.4.4 Galvanic Corrosion

When two different metals or alloys come in contact with each other. The less noble metal corrodes protecting the other cathodically. To avoid galvanic corrosion insulating gaskets are used in practice to isolate them electrically. Following are the some of the common metals and alloys are increasing order of nobility in seawater.

- Aluminum
- Mild steel
- Stainless steel
- Admiralty brass & Copper.

1.4.5 Corrosion In Concrete

Concrete is a widely used structural material that is frequently reinforced with carbon steel reinforcing rods, post-tensioning cable or pre stressing wires. The steel is necessary to maintain of the structure, but it is subject to corrosion.

1.5 Mechanism Of Corrosion

1.5.1 GENERAL

Concrete normally provides excellent corrosion protection for reinforcing steel due to the high pH value of hydrated cement. The high alkaline environment results in formation of a tightly adhering film which passivates the steel and protects it from corrosion. The long-term durability of this protection against corrosion is connected with the stability of conditions necessary for the passive layer.

Deterioration of concrete structures takes place mainly by (a) disintegration of the structure, (b) corrosion of reinforcing steel.

1.5.2 Disintegration of Concrete

In most of the cases, the serious disintegration is due to chemical attack on highly permeable concrete. The common forms of chemical attack are the leaching out of cement and action of sulphates and acidic waters. In case of sea structures, the amount of deterioration is large.

Sulphates solutions present in Seawater react with hydrated cement paste and produce in soluble salts. The salts have a considerably larger volume than the compounds they replace. The end products of the reaction thus lead to progressive cracking and spalling of the concrete. Carbon dioxide and various types of acids that may be present in seawater or produced by micro organisms can dissolve calcium hydroxide, thus causing surface erosion.

Cement containing more than 8% tricalcium aluminates can lead to the replacement of calcium compounds in the hydrated cement by magnesium compounds for the seawater. This results in serious loss of strength.

High chloride concentration in the concrete mix or in water corrosion, particularly when the concrete is low quality with high water cement ratio.

In addition to the chemical action, crystallization of various sea salts may take place in the pores of the concrete due to capillary intrusion of saline water and alternate wetting and drying conditions. Gradual accumulation of these salts may result in the disruption of concrete owing to the bursting pressure exerted by the salt crystals.

Unsound and reactive aggregates in concrete may expand due to prolonged immersion in seawater producing cracking and general disintegration.

1.5.3 Corrosion of Reinforcing Steel

The reinforcement is generally in a passive state up to initiation of corrosion and after initiation, the environment in concrete up to cracking and later by the environment itself influences it. The major factors governing the rate of corrosion are the metallurgical composition of steels, surface characteristics and mechanical working on steel. The corrosion of embedded steel in concrete structure is mainly due to aggressive salts. Concrete usually provides embedded steel with a high degree of protection against corrosion.

This is due to the fact that the liquid phase of concrete normally has a pH value in excess of 12.5 (ranging between 12.5 to 13.2) this alkaline environment; a thin protective coating Fe_2O_3 is formed on steel surface. This protective coating remains intact at high pH values (around 13). The protection afforded to steel by high pH value persists while concrete sets and hardens and remains intact so long as the concrete environment surrounding the steel does not change significantly.

Once the hardened concrete has dried to equilibrium moisture content, the combined protection of steel depends entirely on the ability of the concrete to maintain the appropriate alkaline environment.

However, in seashore structures the protective film of Fe_2O_3 on the steel surface is usually disrupted when the pH value is reduced by ingress of sea salts due to capillary action, cracking and spalling of concrete and poor construction practices. The disruption of protective cover leads to corrosion attack on the reinforcements. Once this attack commences, corrosion products start to build up on the steel surfaces. Gradual accumulation of these products in the development of disrupting tensile forces, which may rupture the surrounding concrete and expose the steel bars to corrosion element.

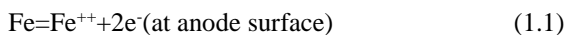
Steel in concrete is generally known to be highly resistant to corrosion, sometimes that steel is protected from corrosion by ferric oxide, (Fe_2O_3) surface film (approximately 1000 Å thick), passivating the steel against corrosion. For corrosion to begin, this film must be broken or depassivated. The depassivation could happen if the alkalinity of pore water in concrete decreases. This can be caused by carbonation, especially near cracks, or dilution, which accompanies cracking.

However, the depassivation due to the basicity of concrete due to the presence crystalline $\text{Ca}(\text{OH})_2$ is so high that the pH is essentially constant even when a great amount of chloride ions penetrate into concrete. Thus the depassivation must be caused directly by corrosive anions, of which Cl is the most important; depassivation is thus induced directly by reaching a threshold concentration of Cl in concrete in the immediate vicinity of the steel surface. In some situation, no protective oxide film might exist and corrosion might be initiated by the formation of a chloride-ion film can form at the steel surface only if the Cl concentration exceeds a certain threshold value.

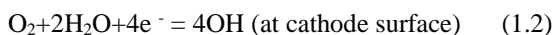
Both things are essentially the same, since the both cases it is the attainment of certain Cl concentration exceeds a certain threshold value.

Both things are essentially the same, since the both cases it is the attainment of certain Cl concentration the initiates the corrosion process. This process consists of dissolution of iron in pore water, or iron is oxidized.

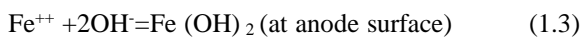
Electrochemical reaction producing rust



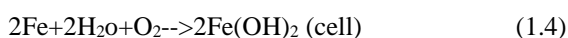
This reaction occurs at tiny anodic areas, which later become densely and uniformly distributed, forming large anodic area. The areas of steel surface that are adjacent to the anodic areas begin to function as cathodes and the oxide film will exist there. The electrons liberated in the anodic area (eqn 1.1) move through steel towards the cathodic area, creating in steel an electric current, which flows from the cathodic to anodic area. Simultaneously, with chloride ions, oxygen that is dissolved in seawater diffuses through concrete towards the steel. In the cathodic region, oxygen dissolved in pore water through concrete towards the steel. In the cathodic region, oxygen dissolved in pore water reacts with the incoming electrons, e from the steel bar in the presence of water to form hydroxyl ions, OH⁻; (reduction of oxygen)



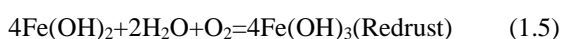
The electric current passes through the electrolyte in the pores of concrete by means of a transfer of negative ions, OH⁻ towards the anode. The hydroxyl ions that arrive at the anodic areas electrically neutralize the Fe⁺⁺ dissolved in pore water, forming a solution of ferrous hydroxide as described by the equation.



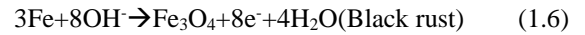
The ferrous hydroxide further reacts with available oxygen and water resulting in Total cell reaction summarizing the equation (1.1-1.3) is



The ferrous hydroxide further reacts with available oxygen and water resulting in



The $\text{Fe}(\text{OH})_3$ constitutes hydrated red rust, the final product that precipitates from the solution.



The black rust may also form at oxygen-limited areas though direct reaction with hydroxyl ion. It is the red rust that is responsible for the cracking of concrete, because its volume is four times large as that of steel, while the black rust volume is only twice as large.

1.6 Symptoms of Corrosion

A symptom of corrosion depends upon the nature of the corrosion product and the quality of concrete cover. If the concrete cover is porous or if there are cracks in the concrete, rust stains will appear on the surface. If concrete cover has good strength corrosion products will create internal pressure [because of their higher densities] and concrete will spall when the internal pressure exceeds its strength. However, the spalling depends whether general corrosion or localized corrosion is occurring. It has been reported that in the case of localized leading to formation of magnetite (Fe_3O_4) spalling may not occur until considerable conversion had occurred

1.7 Methods of Corrosion Control

1.7.1 General

The nature and severity of the problem of chloride deterioration of reinforcing steel in concrete have been studied. The following methods either prevent the problem of corrosion of steel during initial design and installation or allow efficient repair or rehabilitation procedures, which will extend the life of structures that is deteriorating due to corrosion of reinforcing steel.

1.7.2 Corrosion Control By Coatings

Coating in most cases serve as a means of isolating embedded steel from the surrounding environment. Thus an intact coating shields the steel from the various adverse conditions occurring at the concrete steel interface which can cause corrosion of the steel and subsequent failure of the structures. In general the coatings can be said to shield the steel from corrosive solutions and water. Coating of reinforcing steel is generally used to eliminate the effect of some anticipated factor, which would promote corrosion.

1.7.3 Coatings on Reinforcement

A protective anti-corrosive treatment to the steel reinforcement before it is laid in concrete can guard against this chloride corrosion of steel. Currently three types of coatings are being used. They are

- Galvanizing
- Fusion bonded epoxy coating
- Cement based coating
- Coatings on concrete

1.7.4 Corrosion Control By Cathodic Protection

The cathodic protection works on the principle that it prevents corrosion of reinforcement by imposing an over widening potential by applying current externally that forces

all the rebar to act as cathode. Hence the reinforcement is made negatively charged. The protection current overrides any corrosion current flowing between areas within the reinforcement that were previously anodic and cathodic and it stops further corrosion. There are two types of cathodic protection systems.

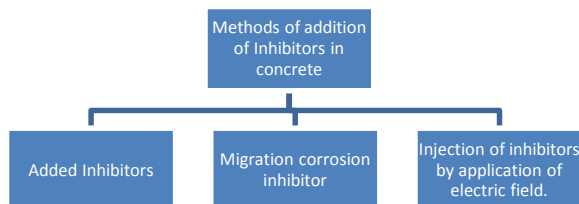
- Sacrificial anode system
- Impressed current system

In sacrificial anode system, the metal which is more anodic to steel such as Zn, Mg, and Al are used as anode and coupled with rebar embedded in concrete structures. The potential difference between anode and steel creates the driving force and causes current to flow from anode to steel. In case of impressed current system, insoluble anode is placed at surface of the concrete near the steel reinforcement and connected to the positive terminal of a D.C. power source and rebar is connected to the negative terminal.

1.7.5 Corrosion Control By Inhibitors

A corrosion inhibitor is an admixture that is used in concrete to reduce the corrosion of rebar. Both organic and inorganic type of inhibitors is widely used in concrete. This has been considered as one of the most cost-effective solutions to the wide spread corrosion problem due to their convenient and economical application to both new structures and repair of existing buildings.

According to NACE (National Association of Corrosion Engineers) inhibitors are substances which when added to an environment, decreases the rate of attack on a metal. Corrosion inhibitors function by reinforcing the passive layer or by forming oxide layer or by forming oxide layer and prevent outside agents from reacting with it. Based on the mode of action, these inhibitors are classified as anodic inhibitors and cathodic inhibitors. Anodic inhibitors decrease the rate of dissolution process by forming thin oxide layer and shielding the anodic sites and reduce the corrosion current. Calcium nitrite, Sodium nitrite, Sodium tetra borate, Sodium benzoate and Zinc borate are some of the inorganic inhibitors used in concrete. Nowadays, organic inhibitors called migrating corrosion inhibitors based on amines and alkanolamine are being tried in some of the structures. They reportedly diffuse through the concrete and protect the reinforcement against corrosion. Injection of synergistic corrosion inhibitors by applying an electric field has also been tried.



1.7.6 Added Inhibitors

In this method inhibitors are added during casting of concrete. Calcium/ Sodium nitrite, Sodium tetra borate, Sodium benzoate, Zinc borate is some of the inorganic inhibitors used in concrete. The amount of inhibitor added normally is in the range 10-15 ml/m³ of concrete. These inhibitors function by reinforcing the passive layer or by forming oxide layer and preventing chloride ions reacting with it this method can be adopted newly constructed structures.

1.7.7. Migration of Corrosion Inhibitors

In this method inhibitor solution is sprayed / pounded on the outer surface of hardened concrete. Then this inhibitor migrates through the concrete capillary structure, first by liquid diffusion via the moisture that is normally present in concrete, then by its high vapour pressure and finally by the following hairlines and micro cracks. Migrating corrosion inhibitors are based on amino-carboxyl ate compounds. These inhibitors protect the steel by forming a monomolecular film between metal and water. These molecules arrange themselves parallel to one another and perpendicular to the reinforcement forming a barrier. The diffusion process requires time to reach the rebar surface.

1.7.8 Electro Migration of Corrosion Inhibitors

In this method inhibitors are injected into the concrete by applying electrical field. Inhibitors are either sprayed or pounded on the hardened concrete and then diffusion process is accelerated by applying appropriate current density. This is done by placing anode on the top surface and making rebar as cathode. Advantage of this method over the above two methods is that, when applying current to chloride present in concrete, is removed simultaneously and all the inhibitors are carried very near to the rebar surface thus substantially reducing the corrosion of rebar. Positively charged quaternary Ammonium and Phosphonium Nitrite, Tetra methyl Ammonium Chloride. These inhibitors protect the steel surface by forming a protective passive layer. By accelerating the diffusion process, this method requires lesser time to reach the rebar surface. Migrating and electro migration of inhibitors can be adopted as a repair method to rehabilitate the corroded concrete structures.

1.8 Fly Ash Blended Cement Concrete

Fly ash is the non-combustible mineral portion of coal, general in coal combustion power plant. Fly ash particles are typically finer than cement particles. It is acidic in nature. Its main constituents are silica, alumina and oxides of iron, calcium and magnesium. The fly ash resembles a pozzolana (i.e.,) a substances which combines with a lime to form a material having cementing properties. The characteristics of fly ash depend upon the type of coal used. Degree of pulverization. Type of furnace used, method of collection and storage etc., thus the fly ash is to be placed some percentage to make a concrete which is said by fly ash blended cement concrete.

2. MIX PROPORTIONING

The aim of the present study is to thoroughly investigate all the strength and behavior characteristics, micro structural properties and corrosion resistance characteristics of the fly ash blended cement concrete experimentally and compared with the change in the above strength, properties and characteristics by the addition of 3% of Diethanolamine as corrosion inhibitor.

2.1 Materials Used

The following materials were used for electro injection of corrosion inhibitors in conjunction with the removal of chloride in concrete.

2.1.1 Ordinary Portland cement: conforming to IS456-2000-43 grade

2.1.2 Graded fine aggregates

2.1.3 Graded coarse aggregates

2.1.4 Water

2.1.5 Cold Twisted Deformed rebar's

2.1.6 Organic inhibitors

2.1.7 Fly ash from Thermal power station.

Diethanolamine –D

The following table indicates the chemical properties of above said organic inhibitors.

CHEMICAL PROPERTIES OF ORGANIC INHIBITOR

TABLE 2.1 Properties of Diethanolamine

S.NO	Inhibitor	Melting point(°c)	Boiling point(°c)	Molecular weight	Molecular formula
1.	Diethanolamine	114.75	89.4	101.19	C ₆ H ₁₅ N

2.2 MIX PROPORTIONING

The quality of concrete mainly depends upon the proportioning of its constituent materials. The mix proportioning mainly influences the permeability of concrete and cause corrosion. Design mix is more appropriate to know the exact behavior of corrosion of steel proportion of 1:1.42:3.28 with water w/c of 0.48.

2.3 Materials Used

2.3.1 Cement

Brand name : ACC CEMENT
 Type : Ordinary Portland cement
 Grade : 43
 Specific gravity : 3.15

2.3.2 Fine Aggregate

Zone : Conforming Zone II

Specific Gravity : 2.6

2.3.3 Coarse Aggregate

Specific Gravity : 2.95

2.3.4 Fly Ash

The Fly Ash Used In This Project Was Obtained From Mettur Thermal Power Plant.

2.4 Mix Design

The aim of studying the various properties of materials of concrete. Plastic concrete and hardened concrete is to design a concrete mix for particular strength. Design of concrete mix needs complete knowledge of the various properties of the constituent material, the implications in place of change on the conditions at site, the impact of the properties of plastic concrete on the hardened concrete and the complicated interrelationship between the variables. Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The mix design procedure is explained in the following section.

2.5 Indian Standard Method

2.5.1 Design stipulations

The required characteristics compressive strength of concrete in the field 28 days of curing is 30N/mm².

The maximum size of the aggregate to be used is 20mm.

The degree of workability and quality control is good.

Slump : 86mm

Compaction factor : 0.9

Type of exposure : MILD

2.5.2 Data About Materials

- A. Ordinary Portland cement (43 Grade)
- B. Fine aggregate confirming to zone of IS 383 -1970
- C. Specific gravity of cement, fine aggregate and coarse aggregate is 3.15,3.2 and 2.95 respectively

2.6 Mix Design Procedure

3.6.1 Target mean strength (F_{ck})

The target mean Compressive strength at 28 days is given by

$$F_{ck} = f_{ck} + t.S$$

Where f_{ck} is 20 N/mm², S is the standard deviation (from Table 1, IS 10262 -1982) and t is the risk factor, which is a statistical value depending on expected proportion of low results.

$$S = 4(\text{for M20 concrete and quality control good})$$

$$t = 1.65 \text{ (Table 2, IS 10262 – 1982 for not more than 5\% of the results which expected to fall)}$$

$$f_{ck} = 20 + 1.65 \times 4.6$$

$$= 27.6 \text{ N/mm}^2.$$

2.6.2 Selection of w/c ratio

This can be obtained by generalized relation between free w/c ratio & compressive strength and durability requirements (Maximum =0.55) whichever is less first option is preferred i.e. the generalized relation between free w/c ratio & compressive strength which has a graph given IS 10262 (figure -1). From the graph for $F_{ck}=27.6 \text{ N/mm}^2$ the corresponding w/c ratio is 0.48.

2.6.3 Estimation of entrapped air

Entrapped air can be obtained as % of volume of concrete based on the maximum size of aggregate used.

In this mix design the maximum size of aggregate used is 20 mm; hence entrapped air is 2% of the volume of concrete.

Selection of water and fine to total aggregate ratio

The water content and percentage of sand of total aggregate by absolute volume are determined based on tables given on IS 10262, which is based on the following conditions. Coarse aggregate conforming to IS 383 – 1970, fine aggregate conforming to grading zone of IS 383 – 1970, workability corresponds to compacting factor of 0.8. Adjustments given in code can be made those which are not conforming to conditions given above. Table IV of IS 10262 is given below which is applicable for concrete up to grade M35.

2.6.4 Approximate sand and water content per m³ of concrete

$$\text{Workability} = 0.9 \text{ compacting factor,}$$

$$\text{W/c} = 0.48$$

Table 2.2 Adjustment for water content and sand

Change in condition	Adjustment	required in
	Water content %	% sand in total aggregate
1. for decrease in w/c ratio by (0.6-0.48) =0.12	0	-2
2. for increase in compacting factor (0.9 -0.8) = 0.1	+3	0
3. for sand conforming to zone II of 383 -1970	0	0

From the adjustments made it is seen that water content has to be increased by 3% and sand content to be reduced by 2% with respect to table IV of IS 10262.

$$\text{Required water content} = 191.60 \text{ lit/m}^3$$

$$\text{Required sand content as percentage of total aggregate by absolute volume} = 38 - 2$$

$$= 33\%$$

2.6.5 Determination of cement content

$$\text{W/c} = 0.48$$

$$\text{Water (w)} = 191.60 \text{ lit m}^3$$

$$\text{Cement (c)} = 399.170 \text{ kg/m}^3$$

2.6.6 Determination of coarse and fine aggregate contents

Absolute volume V is given by,

$$v = [w + (C/S_c) + (1/P) (F_a / sf_a)] \times 1/1000$$

$$\text{And } v = [w + (C/S_c) + (1/P) (C_a / sf_a)] \times 1/1000$$

Where,

$$V = \text{absolute volume} = (1 - 0.02) = 0.98$$

$$W = \text{mass of water} = 191.60 \text{ lit/M}^3$$

$$C = \text{mass of concrete} = 399.17 \text{ kg/M}^3$$

$$S_c = \text{specific gravity of cement}$$

$$F_a, C_a = \text{mass of fine aggregate and coarse aggregate}$$

$$Sf_a = \text{specific gravity of fine aggregate}$$

$$Sc_a = \text{specific gravity of coarse aggregate}$$

$$P = \text{ratio of fine aggregate to total aggregate by absolute volume}$$

By substituting the corresponding values in the above formula mass of fine aggregate and coarse aggregate (Kg)/m³ of concrete can be obtained.

$$F_a = 567.72 \text{ Kg /m}^3$$

$$C_a = 1307.81 \text{ kg /m}^3$$

Water (kg/m ³)	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)
131.60	399.17	567.72	1307.81
0.48	1	1.42	3.28

Mix Proportion

In this study, total of five different mixes were employed to cast specimen, contains all the ingredients of the conventional concrete with design mix ratio of **1: 1.42: 3.28** and characteristic compressive strength of 20 Mpa. This control specimen is designated as mix CS. all the other mixes contained classes C fly of fly ash by weight of Portland cement replaced. The proportion of port land cement replaced was 10, 20, 30 and 40 percent and were designated as mix P1, P2, P3 &P4 Respectively. The mix proportions are given in table. For control specimen the w/c ratio is 0.48. The same amount of water is used for all other specimen. The following table shows the mix proportion used for all other specimens. In this study the effect of organic inhibitor – Diethanolamine in concrete is studied. The inhibitor is added in various % of 1%, 2%, 3% & 4% by weight of cement. Inhibitor added in concrete with correct proportions and proper curing makes a substantial improvement in enhancing the protection of embedded reinforcing steel in concrete from corrosive agents. It was designated as mix D1, D2, D3 and D4 respectively.

Table 2.3 Mix proportions of fly ash

Mix	Cement kg /m ³	FA kg /m ³	CA kg /m ³	Fly Ash kg /m ³	Water kg /m ³
CS	399.17	567.72	1307.81	-	191.60
P1	359.25	567.72	1307.81	39.92	191.60
P2	319.34	567.72	1307.81	79.83	191.60
P3	279.42	567.72	1307.81	119.75	191.60
P4	239.50	567.72	1307.81	159.67	191.60

FA -fine aggregate, CA – coarse aggregate

Table 2.4 Mix Proportions of Inhibitors

Mix	Cement kg /m ³	FA kg /m ³	CA kg /m ³	Fly Ash kg /m ³	inhibitor	Water kg /m ³
CS	399.17	567.72	1307.81	-	-	191.60
D1	359.25	567.72	1307.81	39.92	3.6	191.60
D2	319.34	567.72	1307.81	79.83	6.4	191.60
D3	279.42	567.72	1307.81	119.75	8.4	191.60
D4	239.50	567.72	1307.81	159.67	9.6	191.60

FA -fine aggregate, CA – coarse aggregate

3. RELIABILITY ANALYSIS

3.1 Introduction

The concept of reliability has been applied to many fields and has interpreted in many ways. The most common definition and accepted by all, of reliability is that reliability is the probability of an item performing its intended function over a given period of time under the operating conditions encountered. it is important to note that the above definition stresses four significant elements, viz.(i) probability,(ii) intended function ,(iii)time , and (iv) operating conditions. Because of the uncertainties, the reliability is a probability which is the first element in the definition. The second point, intended function, signifies that the reliability is a performance characteristic.

For a structure to be reliable, it must perform a certain function or function satisfactorily for which it has been designed, i.e. safety against shear or flexure or torsion, etc. the reliability is always related to time. In the case of structure, it is related to the life time of the structure. During this specified life of the structure, it must perform the assigned function satisfactorily. The point is the operating conditions. This establishes the actions or stresses that will be imposed on the structure. These may be loads, temperature, shock, vibrations, corrosive atmosphere, etc reliability also change with respect to quality control, workmanship, production procedure , insection, etc

3.2 RELIABILITY INDEX

If the failure function is linear and the basic random variables are normally distributed, then the following relationship may be obtained

$$P_f = \Phi (-\beta)$$

Where Φ is the standard normal cumulative distribution function and β is termed the reliability index and defined by

$$\beta = \frac{\mu_m}{\delta_m}$$

Where μ_m and δ_m are the mean and standard deviation of M, respectively

3.3 RESISTANCE MODELS

Three limit states were considered in the analysis of the deteriorating beams:

- Moment resistance
- Shear resistance
- Combined moment and shear, or ‘bond’

4. RESULTS AND DISCUSSIONS

4.1. STRENGTH TESTS

4.1.1. Compressive strength for various mix proportions of fly ash (N/mm²)

Table 4.1. Compressive Strength (N/mm²)

Specimen	3- Days	7-Days	28-Days
CS	14.29	21.54	27.73
P1	15.42	22.21	28.27
P2	16.45	23.05	28.82
P3	17.57	24.31	30.27
P4	14.07	20.56	25.30

From the Table 4.1, it is seen that the strength of the specimen increases with increase in fly ash content up to 30%. But with 40% replacement of fly ash, the strength reduced to the value below that of the control specimen. The mixes with 30% fly ash 16% more compressive strength than the control specimen.

4.1.2. Compressive strength with various proportions of fly ash with Diethanolamine Inhibitor (N/mm²)

Table 4.2. Compressive Strength with Inhibitor (N/mm²)

Specimen	3-Days	7-Days	28-Days
CS	14.29	21.54	27.73
D1	17.83	24.54	28.43
D2	18.46	25.79	29.22
D3	18.79	25.91	31.06
D4	17.97	23.97	28.85

From the Table 4.2, it is seen that mix P3 with addition of 3% inhibitor has shown improvement in compressive strength when compared to the control specimen. The 3% inhibitor having 18% more compressive strength than control specimen.

4.1.3. Split Tensile Strength for various mix proportions of fly ash (N/mm²)

Table 4.3. Split Tensile Strength (N/mm²)

Specimen	3-Days	7-Days	28-Days
CS	1.69	2.31	2.61
P1	1.80	2.50	2.82
P2	1.82	2.62	2.93
P3	1.95	2.91	3.15
P4	1.53	2.08	2.52

From the Table 4.3, it is obvious that all the fly ash replaced specimen have shown increase in strength when compared to control specimens. The mix P3 with 30% fly ash shows 20.68% increase in strength more than control specimen.

4.1.4. Split Tensile Strength with various proportions of fly ash with Diethanolamine Inhibitor (N/mm²)

Table 4.4. Split Tensile Strength with inhibitor (N/mm²)

Specimen	3-Days	7-Days	28-Days
CS	1.69	2.31	2.61
D1	1.98	2.98	3.32
D2	2.19	3.46	3.59
D3	2.45	3.79	3.84
D4	1.69	2.39	2.96

From the Table 4.4, it is seen that mix D3 with addition of 3% inhibitor has shown improvement in Split Tensile Strength when compared to the control specimen. The 3% inhibitor having 22% more compressive strength than control specimen.

4.1.5. Flexural Strength for various mix proportions of fly ash (N/mm²)

Table 4.5. Flexural Strength (N/mm²)

Specimen	3-Days	7-Days	28-Days
CS	3.45	4.79	7.22
P1	2.93	3.60	7.74
P2	2.74	4.34	7.92
P3	3.32	4.87	8.10
P4	2.52	3.91	7.45

From the Table 4.5, it is seen that the strength of the specimen increases with increase in fly ash content up to 40% replacement of fly ash, the strength reduced to the value below that of the control specimen. The mixes with 30% fly ash 13% more flexural strength than the control specimen.

4.1.6. Flexural Strength with various proportions of fly ash with Diethanolamine Inhibitor (N/mm²)

Table 4.6. Flexural Strength with inhibitor (N/mm²)

Specimen	3-Days	7-Days	28-Days
CS	3.45	4.79	7.22
D1	3.49	4.92	8.26
D2	3.86	4.99	8.93
D3	3.98	5.10	9.30
D4	2.97	4.60	8.37

From the Table 4.6, it is seen that mix D3 with addition of 3% inhibitor has shown improvement in Flexural Strength when compared to the control specimen. The 3% inhibitor having 15% more compressive strength than control specimen.

4.1.7. Pull out/Bond Strength for various mix proportions of fly ash (N/mm²)

Table 4.7. Pull out/Bond Strength (N/mm²)

Specimen	3-Days	7-Days	28-Days
CS	7.28	8.48	10.28
P1	7.44	9.24	11.45
P2	6.52	8.96	11.81
P3	7.55	9.81	12.80
P4	7.13	8.35	10.47

All fly ash replaced specimens except P4 have shown improvement in bond strength when compared to the control specimen. Mix P3 has shown 24.5% increase in bond strength when compared to the control specimen.

4.1.8. Pull out/Bond Strength with various proportions of fly ash with Diethanolamine Inhibitor (N/mm²)

Table 4.8. Pull out/Bond Strength with inhibitor (N/mm²)

Specimen	3-Days	7-Days	28-Days
CS	7.28	8.48	10.28
D1	7.94	10.28	11.90
D2	8.13	10.50	13.23
D3	8.60	10.97	13.31
D4	7.06	9.48	12.39

From the Table 4.8, it is seen that mix D3 with addition of 3% inhibitor has shown improvement in Flexural Strength when compared to the control specimen. The 3% inhibitor having 4% more compressive strength than control specimen.

4.2. MICRO STRUCTURAL PROPERTIES (AS PER ASTM C642-97)

4.2.1. Water absorption (Various mix proportions of fly ash)

Table 4.9. Water Absorption

S. No	Specimen	Average Weight (gms)		Water Absorption %
		A	B	
1	CS	755	792	4.90
2	P1	756	794	4.78
3	P2	758	795	4.65
4	P3	760	796	4.52
5	P4	766	802	4.48

As fly ash arrests the percolation voids, the rate of water absorption decreases with increases in percentage of fly ash. The graph shows the gradual decreases in water absorption ratio increase in fly ash content.

4.2.2. Water absorption for various mix proportions of fly ash with Diethanolamine inhibitor.

Table 4.10. Water Absorption with inhibitor

S. No	Specimen	Average Weight (gms)		Water Absorption %
		A	B	
1	CS	755	792	4.90
2	D1	762	797	4.39
3	D2	780	808	3.46
4	D3	796	820	2.92
5	D4	813	832	2.52

With increase in amount of inhibitor at various percentages, the rate of water absorption gets decreased in the specimen with added inhibitor.

4.2.3. Percentage of Permeability (Various mix proportions of fly ash)

Table 4.11. Percentage of Permeability

S. No	Specimen	Average Weight (gms)			Water Absorption %
		A	B	C	
1	CS	750	770	380	5.12
2	P1	755	774	385	4.88
3	P2	775	775	387	4.38
4	P3	776	776	388	4.12
5	P4	778	778	389	3.85

Fly ash reduces the permeability. As similar to water absorption, permeability also shows decrease in values with increase in percentage as fly ash.

4.2.4. Percentage of Permeability for various mix proportions of fly ash with Diethanolamine inhibitor.

Table 4.12. Percentage of Permeability with inhibitor

S. No	Specimen	Average Weight (gms)			Water Absorption %
		A	B	C	
1	CS	750	770	380	5.12
2	D1	763	778	389	3.90
3	D2	764	779	389	3.84
4	D3	766	780	390	3.58
5	D4	768	781	391	3.33

Since the percentage of inhibitor goes on increasing, the permeability through the specimen gets gradually from control specimen to mix D4.

4.2.5. Bulk Density (Various mix proportions of fly ash)

Table 4.13. Bulk Density (gm/cm³)

S. No	Specimen	Average Weight (gms)	Volume (cm ³)	Bulk Density (gm/cm ³)
1	CS	805	340.47	2.36
2	P1	825	340.47	2.42
3	P2	838	340.47	2.46
4	P3	852	340.47	2.50
5	P4	867	340.47	2.55

Ash the density of concrete increases, the bulk density also increases. Addition of fly ash increases the density and within fly ash the bulk density correspondingly increases.

4.2.6. Bulk Density for various mix proportions of fly ash with Diethanolamine inhibitor.

Table 4.14. Bulk Density with inhibitor. (Gm/cm³)

S. No	Specimen	Average Weight (gms)	Volume (cm ³)	Bulk Density (gm/cm ³)
1	CS	805	340.47	2.36
2	D1	869	340.47	2.55
3	D2	878	340.47	2.57
4	D3	886	340.47	2.60
5	D4	914	340.47	2.68

As the density of concrete increases, the bulk density also increases. Addition of inhibitor increases the density and with increase in inhibitor the bulk density correspondingly increases.

4.3 durability Test

4.3.1. Weight loss Rod Method (various mix proportions of fly ash)

Table 4.15. Weight loss Rod Method

Specimen	W1	W2	Corrosion Rate (mmpy)	Avg Corrosion Rate (mmpy)
CS	228	227.00	0.087	0.078
	226	225.20	0.054	
	227	226.25	0.093	
P1	229	228.25	0.062	0.062
	227	226.35	0.054	
	226	225.40	0.070	
P2	230	229.65	0.070	0.055
	227	226.60	0.054	
	229	228.55	0.042	
P3	229	228.55	0.062	0.047
	226	225.55	0.049	
	228	227.40	0.030	
P4	230	229.65	0.034	0.036
	228	227.60	0.049	
	229	228.55	0.030	

The increase in percentage of fly ash decreases the corrosion rate. Thus the loss in weight rebar reduces with increased fly ash percentages.

4.3.2. Weight loss Rod Method for various mix proportions of fly ash with Diethanolamine inhibitor.

Table 4.16. Weight loss Rod Method with inhibitor

Specimen	W1	W2	Corrosion Rate (mmpy)	Avg Corrosion Rate (mmpy)
CS	228	227.00	0.087	0.078
	226	225.20	0.054	
	227	226.25	0.093	
P1	227	226.35	0.038	0.040
	228	227.50	0.041	
	226	225.55	0.042	
P2	230	229.50	0.038	0.036
	226	225.40	0.041	
	228	227.45	0.042	
P3	227	226.40	0.041	0.031
	228	227.60	0.025	
	226	225.55	0.028	
P4	229	228.55	0.028	0.028
	226	225.50	0.034	
	228	227.65	0.022	

The increase in percentage of inhibitor decreases the corrosion rate. Thus the loss in weight rebar reduces with increased inhibitor percentages.

4.3.3. Reliability Index.

Table 4.17. Reliability Index (various percentage of fly ash)

Specimen	Years	Reliability Index
CS	2010	12.11
	2015	11.01
	2020	9.10
	2025	6.30
	2030	3.20
P1	2010	12.11
	2015	11.40
	2020	9.65
	2025	7.20
	2030	3.80
P2	2010	12.11
	2015	11.85
	2020	10.80
	2025	8.84
	2030	5.80
P3	2010	12.11
	2015	12.10
	2020	11.35
	2025	9.90
	2030	7.30
P4	2010	12.11
	2015	12.50
	2020	12.00
	2025	10.70
	2030	8.30
	2010	5.50

Corrosion initiation time for CS, P1, P2, P3, P4 are 15 years, 17 years, 20 years, 22 years and 25 years respectively.

4.3.4. Reliability Index of fly ash with inhibitor

Table 4.18. Reliability Index of fly ash with inhibitor

Specimen	Years	Reliability Index
CS	2010	12.11
	2015	11.01
	2020	9.10
	2025	6.30
	2030	3.20
D1	2010	12.11
	2015	11.35
	2020	10.01
	2025	7.60
	2030	4.52
D2	2010	12.11
	2015	11.79
	2020	10.80
	2025	8.80
	2030	5.84
D3	2010	12.11
	2015	12.05
	2020	22.20
	2025	9.50
	2030	6.95
D4	2010	12.11
	2015	12.31
	2020	11.65
	2025	10.20
	2030	7.80
	2034	5.65

Corrosion initiation time for CS, D1, D2, D3 and D4 are 16 years, 18 years, 21 years, 23 years and 26 years respectively.

5. CONCLUSION

- The specimens were cast with fly ash of varying percentage of 10, 20, 30 and 40 by weight of cement and for the optimal percentage Diethanolamine inhibitor of varying percentage of 1%, 2%, 3% and 4% weight of cement are added.
- The specimens cast with fly ash have shown better performance in strength tests. The compressive, split tensile and bond strength of the concrete specimen cast with 30% fly ash attained the maximum values. It was observed that there was 16% increase in compressive strength, 20.68 % increase in split tensile strength, 13 % increase in flexural strength and 24.50% increase in bond strength.
- For the 30% replacement of cement with fly ash is added various percentage of Diethanolamine inhibitor and it is observed that 3% added inhibitor attained the maximum values. It was observed that there was 18% increase in compressive strength, 22 % increase in split tensile strength and 4 % increase in bond strength.
- Micro structural studies reveal that the fly ash when added reduces the percentage of water absorption and permeability of concrete considerably. The specimen with 30% fly ash shows decrease in water absorption and 20% decrease in permeability when compared with control specimen.
- Polarization test results prove that increase in percentage of fly ash increases the corrosion initiation time. Corrosion was initiated in the steel embedded in control specimen (30 % fly ash and 0% inhibitor) at 150hrs (6.25days), whereas the corrosion initiation time for 1%, 2%, 3% and 4% are 178.66hrs (7.44days), 206.66hrs (9.2days), 262hrs (11days) and 183.33hrs (11.8days) respectively. This shows that there is an increase in resistance of 19%, 38%, 70% and 88% respectively.
- The half-cell potentiometer readings also conform that the corrosion initiation time increases to increase in fly ash percentages.
- The weight loss rod method proves that increase in inhibitor percentages decreases the corrosion rate. The specimen with 3% inhibitor has shown a decrease in weight of only 26% when compared that of control specimen.
- It is observed that 30% fly ash replaced concrete with 3% addition of Diethanolamine inhibitor has shown the optimal performance in both strength and durability aspects.
- The reliability analysis results also substantiate that increase in percentage of fly ash increases the corrosion initiation time. Corrosion was initiated in the steel embedded in control specimen after 15 years, whereas the corrosion initiation time for 10%, 20%, 30% and 40% replacement of fly ash are 17years, 20years, 22years and 25years respectively.

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