

An Experimental Investigation To Enhance Strength Characteristics And Corrosion Resistance of Concrete By Using Aluminium Oxide As An Admixture

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Abstract- Building plan optimization performs an important function in maximizing the reliability, value efficiency, and environmental sustainability of built facilities. As the development of Reinforced Concrete (RC) buildings consumes outstanding amounts of steel reinforcement in concrete. Hence the graph of structure below serviceability (or) durability standards is as vital as strength. One necessary standard for is corrosion resistance. Corrosion of strengthened concrete can be seen underneath two customary businesses viz., normal climate corrosion and corrosion underneath the motion of externally utilized chemical agents. Corrosion is nicely greater serious when energetic external chemical agents such as chlorides or sulphates are present.

The purpose of this assignment is to examine the impact of Aluminium Oxide on Compressive Strength of Concrete and to study the effect of lowering the free-chloride content material in the concrete, which is often responsible for corrosion of reinforcement bars.

I. INTRODUCTION

In Construction Industry Structural Safety is as important as Durability. Structural engineers have continually worried themselves with structural safety and rightly so. In many cases, graph for serviceability or durability has been inadequate, partly due to the nature of the substances and diagram methods used, and partially due to the lack of information on serviceability limitations. The use of high energy steels and closing strength plan techniques have led to slim sections and for that reason main to limits on deflections and crack widths. Design engineers now realise that serviceability or durability is as necessary as strength, because a structure, which does now not serve its purposes, is useless. One vital serviceability criterion is corrosion resistance.

Corrosion of Reinforced concrete can be viewed underneath two regular groups: everyday weather corrosion and corrosion beneath the action of externally applied chemical agents. Normal weather corrosion takes region under

the mixed action of oxygen and moisture and is more massive in polluted air environments of a huge city or industrialized area. Corrosion is much greater serious when active exterior chemical agents such as chlorides or sulphates are present. They may also be contained in the soil and be carried to the shape through seeping moisture. Salt, used as de-icer on bridge decks, often penetrates the concrete structural members. Exposure to sea water outcomes in a similar chloride condition.

Chloride-induced corrosion of reinforcing steel is recognised as a primary factor contributing to the deterioration of concrete structural elements.

- i. Moisture,
- ii. Dissolved oxygen in moisture and
- iii. Aggressive ions (particularly chlorides)

Which are the three important factors contributory for induction of corrosion or re-bars. If oxygen and water are eliminated completely, then corrosion will be arrested completely. But, it is normally impossible to eliminate oxygen and moisture from the structural elements, since these are inherently present in the structure, but it is possible to remove the aggressive ions (particularly chlorides) from the structures by electrochemical (desalination) or chemical (complex formation, adsorption) methods.

The electro-chemical method of doing away with free chloride is located to be one hundred percentage feasible for concrete buildings underneath immersed conditions. But, for atmospherically exposed bridges, the technique is no longer observed to be suitable, owing to the excessive electrical resistivity of the concrete. Considering the climatic stipulations in India, the bridges are below dry publicity conditions, most of the time. Under these circumstances, it would be challenging to implement electro-chemical method of doing away with chloride. Moreover, the electro-chemical technique involves sizeable engineering inputs such as anode

design, distribution of anodes and distribution of electric current.

The technique proposed in this experimental work is very simple to use. It can be very effortlessly implemented at some point of the time of construction of bridges or throughout the manufacture of cement itself.

1.1 Factors contribute to corrosion of Reinforced Concrete:

a) P^H value of medium

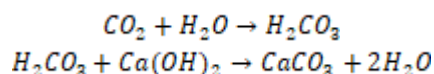
The P^H value is a figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values(0-7) are more acid and higher values(7-14) more alkaline.

Corrosion more rapidly occurs in Acidic solutions than in Alkaline Solutions. The P^H value of Fresh Concrete is about 13 which is highly alkaline. This implies the severity of corrosion at early stage is very much low. However, there is another adverse action called Carbonation which immediately starts to fight with the alkalinity of the concrete.

b) Carbonation

Carbonation of concrete is a process by which carbon dioxide from the air penetrates into concrete through pores and reacts with calcium hydroxide to form calcium carbonates. The pH value of pore water in the hardened cement paste, which was around 13, will be reduced to around 9.0. When all the Ca (OH)₂ has become carbonated, the pH value will reduce up to about 8.3. In such a low pH value, the protective layer gets destroyed and the steel is exposed to corrosion.

The chemical reaction equations are presented here under:



The effect of carbonation is not severe under dry conditions, (but corrosion needs moisture) hence corrosion does not occur rapidly at early stages until and unless Carbonation has occur fully.

c) Moisture

The major constituent to start the corrosion reaction is moisture. All attacking agents such as salts, Carbon dioxide and Oxygen are become unreactive in the absence of moisture.

Corrosion cells will form only when these agents are start reacting under moisture which leads to corrosion.

d) Chloride ion concentration

At low concentrations, chloride ion has little or no effect on the physical stability of concrete structure but it causes the corrosion of the reinforcing steel in the concrete but at high concentration especially at low temperature, it causes expansion and cracking in the concrete. The sodium chloride will reduce the alkalinity of the pore system in the concrete thereby de-passivating the layer that would be formed around the reinforcement. This will lead to further corrosion of the reinforcement in the concrete.

The presence of chloride ions increases the rate of corrosion by increasing the rate of ionic conductivity. Sodium chloride also promotes corrosion by destroying the protective oxide film around the bar surface. The degree of chloride concentration may have two opposing effects: (i) it increases ionic conductivity and (ii) it decreases oxygen solubility at high concentrations.

Consequently, there is a maximum salt concentration above which the rate of corrosion would begin diminishing, due to reduction in oxygen availability as shown in Fig-1.1

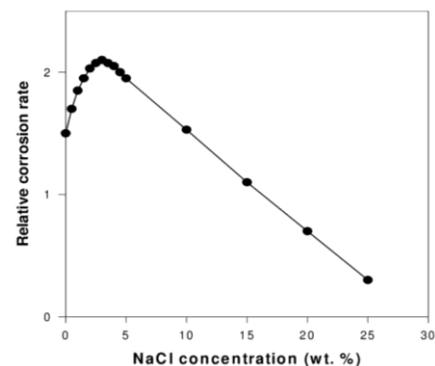


Fig-1.1 Graph between Rate of Corrosion vs Sodium Chloride Concentration

Differential depositions of salts around the reinforcing bars may lead to electrical potential differences and thus increase the probability of corrosion. The presence of salts may also destroy the durability of the concrete cover, mainly due to pressures exerted by the growth of salt crystals.

d) Oxygen availability

Oxygen reacts by consuming electrons at the cathode, causing cathodic depolarization and enhancing the rate of corrosion. Cathodic corrosion can be controlled by prevention

of depolarization, and creating other forms of barriers, such as coatings. Hence corrosion will be stopped when oxygen is eliminated.

Oxygen is necessary to depolarize the cathode and promote continuous reaction. Therefore, when oxygen is eliminated, corrosion has to stop. Complete submergence or protective films (that seal-off oxygen) are commonly used for limiting many corrosion reactions.

II. LITERATURE REVIEW

2.1 Chloride Attack

Of the quite a number harmful anions encountered in concrete structures, chloride has obtained a considerable reputation as the most aggressive ion. Earlier research (Reference No 3) revealed that chloride ions have very high penetrating power through the passive oxide films shaped on metals. This effect is due to its smaller measurement in evaluation to different ions. (The radius of chloride ion 1.81 Å° whereas that of sulphate ion is 2.42 Å°). Among the halide ions, chloride is the most aggressive due to the fact of its smallest size, absolute best mobility and lowest activation energy for de-passivation. Compared to chloride, sulphate ion is less aggressive due to the fact of its larger size and decrease mobility.

Plain concrete is now not chemically affected via chlorides unless they are current in very high; concentrations. The chief thing of injury is the corrosion of metal in reinforced concrete, leading to cracking, and in severe instances of attack, spalling of concrete cover.

Chloride attack is wonderful in that the major action is the corrosion of metal reinforcement, and it is only as a final result of this corrosion, that the surrounding concrete is damaged. Corrosion of reinforcement is one of the predominant motives of deterioration of reinforced concrete constructions in many locations.

Chlorides can be present in concrete due to the fact they may also have been integrated in the mix thru the use of contaminated aggregate, or sea water or brackish water, or by means of admixtures containing chlorides.

The presence of a given excessive quantity of chlorides in the authentic mix, outcomes in a more aggressive motion and consequently a greater corrosion rate, than when the equal amount of chloride has ingress into the concrete in service.

Hydrated cement concrete is alkaline with PH of 12 to 14, due to the formation of calcium hydroxide and the presence of alkalis in cement. In such an alkaline environment, a skinny passivating layer of ferrous hydroxide is formed on the rebar surface which impedes (obstructs) similarly corrosion of the steel, appearing as a defensive bodily barrier to the oxidization agents. This country of steel is regarded as passivation.

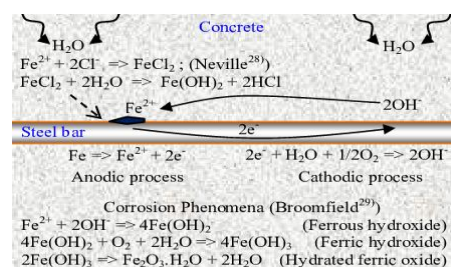
Steel passivity ought to be impaired when chlorides and other corrosion stimulants are current as admixtures ort contaminants in concrete or when they penetrate from outer medium. Hence, metal will corrode and, the corrosion products that occupy a larger quantity than the dad or mum metal produce giant internal stress (sufficient to crack the concrete). After a crack has been fashioned in this way the steel corrodes even greater rapidly and should lead to entire failure of the shape.

2.2 Mechanism of Chloride-induced Corrosion:

Corrosion of reinforcement bar in concrete is an elector-chemical process. To set up and begin a corrosive mechanism, three basic factors are necessary: anode, cathode and electrolyte. An anode is an electron producing unit whilst the cathode is electron ingesting unit. The electrolyte is a medium via which ionic glide can occur.

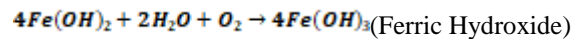
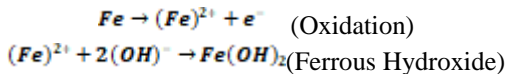
An electrochemical cell is set up, when there exists, a distinction in electric powered plausible alongside the metal embedded in concrete. They structure anodic and cathodic regions, connected via the electrolyte in the form of pore water, in the hardened cement paste.

The positively charged ferrous ions Fe^{2+} at the anode bypass into reply at the same time as the negatively charged free electrons e^- skip via through the steel into the cathode the area they are absorbed via the elements of electrolyte and the mix with water and oxygen to structure hydroxyl ions $(OH)^-$. These tour through the electrolyte and combine with ferrous ions to form ferric hydroxide which is converted with the useful resource of similarly oxidation to form rust (Fig. 3). (Reference No. 2)

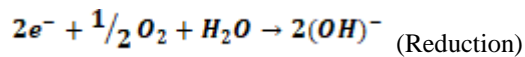


The reactions involved are as follows:

Anodic reactions:

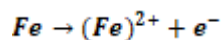


Cathodic reactions:

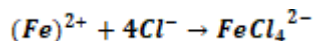


The differences in electrochemical manageable can arise from differences in the surroundings of the concrete. For example, when a section of it is permanently submerged in sea water and a phase is uncovered to periodic wetting and drying. A comparable state of affairs can occur when there are extensive differences in the thickness of cover to a metal machine which is electrically connected. Electrochemical cells form, also, due to model in salt concentration in the pore water or due to a non-uniform get admission to oxygen.

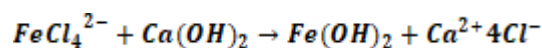
In the passive state of reinforcing bar in concrete, there is equilibrium at the surface of the bar.



Chloride ions form complex salts with ferrous ions:



Since ferrous ions are removed from the steel surface, more of the steel will corrode in order to re-establish the ferrous ion equilibrium. The calcium hydroxide in the concrete mortar phase causes the release of chloride ions which further corrode the steel.



Thus, it is viewed that whereas corrosion of rebar in concrete is averted when PH is increased than 12.5 in presence of oxygen and moisture, chlorides can spoil down the passivation layer and reason corrosion even at enormously alkaline micro environments. Because the electrochemical cell requires a connection between the anode and the cathode by the pore water as well as by way of the reinforcing metal itself, the pore machine in hardened cement paste is a most important element influencing corrosion. In electrical terms, it is the resistance of the “connection” through the concrete that controls the go with the flow of the current. The electrical resistivity of concrete is notably influenced by using its

moisture content, by using ionic composition of pore water if any, with the aid of continuity of the pore system in the hardened cement paste.

There are two consequences of corrosion of steel. First, the merchandise of corrosion occupy a volume numerous instances large than the original metal so that their formation effects in cracking, spalling or delamination concrete. (Reference No 2)

This makes it less complicated for aggressive agents to ingress closer to the metal with a consequent make bigger in the price of corrosion. Second, the progress of corrosion at the anode reduces the cross sectional place of steel as a result lowering its load carrying capacity. In this connection, it be pointed out that chloride-induced corrosion is pretty localized at a small anode and as a result pitting of metal takes place.

2.3 Chloride binding

Chloride ions reside within the concrete system with different amounts of fixity. Part of the chloride ion exists in Free State in the pore water solution whereas the remaining part is bound to the products of hydration of cement by adsorption and chemical reaction. This process of fixing a part of the chloride ions is called “Chloride binding” capacity of concrete. As a very general rule, the bound chloride in ordinary Portland cement paste may vary from 40 to 60 percent of the total chloride ions present.

The main form of binding of the chloride ions is by reaction with C₃A to form calcium chloroaluminate i.e., 3 Ca O Al₂O₃ CaCl₂ 10 H₂O, sometimes referred to as Friedel’s Salt. A similar reaction with C₄AF results n calcium chloroferrite i.e., 3 Ca O Fe₂O₃ CaCl₂ 10 H₂O

The chloride which remains in the pore water i.e., the free chloride is responsible for corrosion of the steel.

More chloride ions are bound when the C₃A content of the cement is higher and also when the cement content of the mix is higher. The cements with a high C₃A contents are conducive to good resistance to corrosion.

It follows that in cement of low aluminate content, less chloride can be combined to form chloro aluminate and a greater portion will remain in the Free State. Corrosion can, therefore, be initiated at lower chloride levels in sulphate resisting Portland cement concrete than in OPC concrete.

III. EXPERIMENTAL INVESTIGATION

The experimental work consists of

1. Casting and curing of concrete cube specimens.
2. Testing for the compressive strength of the concrete cube specimens
3. Carrying out chemical analysis on the powdered samples of the above tested specimens.

3.1 Materials used for experimental work

Cement:The cement used is ordinary portland cement of 43 grade.

Fine Aggregate:Locally available clean river sand (Fineness modulus of sand = 2.6) is used as fine aggregate.

Coarse Aggregate: Locally available graded aggregate of nominal size, greater than 10mm and less than 20mm is used as coarse aggregate.

Water:Distilled water is used for preparing and curing of the Cement concrete cube specimens.

Admixtures: Sodium Chloride (analar grade) and Aluminium Oxide (analar grade) are used as admixtures.

Chemicals:Standard Silver Nitrate Solution, Potassium Chromate Indicator.

Filter Paper:Whatman filter paper No.42 (2.5 µm)

Grade of concrete:

The Cement concrete grade of M₂₅ is designed and used for preparation of Cement concrete cube specimens.

Concrete mix design: (Reference No 1)

Mix design is 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 selection of mix proportions must satisfy not only the strength requirements but must also ensure adequate durability.

From among various methods of proportioning, the Indian Standards method has been adopted for the mix design in the present experimental programme. Indian standard institution has brought out mix design procedure mainly based on work done in national laboratories. This is covered in IS

code No. 10262-2019. This technique can be applied to each medium power and high strength concretes.

3.2 DESIGN OF CONCRETE MIX

Stipulations for Proportioning

- a) Grade designation : **M 25**
- b) Type of Cement : **43** grade Ordinary Portland Cement conforming IS 269-2015
- c) Maximum nominal size of coarse aggregate : 20mm
- d) Minimum amount of cement : 300 kg/m³ as per Table 5 of IS 456-2020
- e) Maximum water-cement ratio : 50 as per Table 5 of IS 456:2000
- f) Workability : 75-125 mm slump
- g) Exposure Condition : Moderate (For Reinforced Concrete)
- h) Method of Concrete Placing : Manual
- i) Degree of Supervision : Good
- j) Type of aggregate : Crushed Angular Aggregates

Test Data for Materials

- a) Cement used : 43 grade Ordinary Portland Cement conforming to IS 269-2015
- b) Specific gravity of Cement : 3.14
- c) Specific Gravity of
 1. Coarse aggregate 20mm : 2.799
 2. Coarse aggregate 10mm : 2.789
 3. Combined SG of aggregate (20mm-60% and 10mm 40%) : 2.795
 4. Fine aggregate : 2.517
- d) Water absorption
 1. Coarse aggregate 20mm : 0.41%
 2. Coarse aggregate 10mm : 0.59%
 3. Fine aggregate : 1.87%
- e) Aggregate impact value : 20.52%
- f) Combined flakiness & Elongation Index : 27.57%
- g) Sieve Analysis
 1. Coarse aggregate : Conforming to all in aggregates of Table 2 IS 383
 2. Fine aggregate : Conforming to Grading Zone III of Table 4 of IS 383

Target Strength for Mix Proportioning

$$f'_{ck} = f_{ck} + 1.65 S$$

(or)

$$f'_{ck} = f_{ck} + X$$

Whichever is higher will be considered

Where,

f'_{ck} = target average compressive strength at 28 days,
 f_{ck} = characteristic compressive strength at 28 days,
 S = Standard deviation, and
 X = factor based on grade of concrete (as per Table 1, IS 10262-2019)

$$f'_{ck} = f_{ck} + 1.65 S \Rightarrow 25 + (1.65 \times 4) = 31.60 \text{ N/mm}^2$$

$$f'_{ck} = f_{ck} + X \Rightarrow 25 + 5.5 = 30.5 \text{ N/mm}^2$$

The higher value to be adopted,
 Therefore, target strength will be **31.60 N/mm²**

Approximate Air Content

From table 3, the approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is 1.0% for 20mm nominal maximum size of aggregate.

Selection of Water-Cement ratio

The free water cement ratio for the target strength of 31.60N/mm² is 0.48 may be used for OPC 43 grade curve.

w/c = 0.48 is lower than the maximum value of 0.50 prescribed from the Table 3 of IS 456:2000 maximum water cement ratio for moderate condition

w/c < 0.48 < 0.5 Hence ok

Selection of Water Content

From Table 4 of IS 10262:2019, maximum water content for 20mm aggregate = 186 litre (for 25-50mm slump range) but for an increase by about 3 percent for every additional 25mm slump so here estimated water content for 125mm slump = 186 + (186 * 9%) = 202 litres

Calculation for Cement Content

As discuss earlier adopted based on trial w/c ratio = 0.48
 Cement content = 202/0.48 = 420.83 kg/m³

From Table 5 of IS 456, minimum cement content for 'moderate' exposure conditions is 300 Kg/m³ but taken 420.83 kg/m³ > 300 kg/m³ hence ok.

Proportion of volume of Coarse aggregate and Fine Aggregate content

As per Table 5 of IS 10262:2019 volume of coarse aggregate for 20mm nominal size aggregate and fine aggregate (Zone III) for having water-cement ratio of 0.5 is 0.64 (a)

In the present case water-cement ratio is 0.48. Therefore, volume of coarse aggregate is required to increase to decrease the fine aggregate content. As the water-cement ratio is lower by 0.02. The proportion of volume of coarse aggregate is increased by 0.012 (at the rate of +/- 0.01 for every +/- 0.05 change in water-cement ratio).

$$\Rightarrow 0.02 / 0.05 = 1.67 \text{ times of } 0.01$$

$$\text{So, } 0.01 \times 1.67 = 0.0167 \text{ (b)}$$

$$= a + b = 0.64 + 0.0167 = \mathbf{0.6567} \text{ (at the rate of } \pm 0.01 \text{ for every } \pm 0.05 \text{ change in water-cement ratio).}$$

Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.48 is **0.6567**

$$\text{Volume of fine aggregate content} = 1 - 0.6567 = \mathbf{0.333}$$

MIX CALCULATIONS

The mix calculations per unit volume of concrete is as follows:

- Volume of concrete = 1m³
- Volume of the entrapped air in wet concrete = 0.01m³
- Volume of cement = mass of cement / (specific gravity of cement x 1000)
 = 420.83 / (3.15 x 1000)
 = 0.133 m³
- Volume of water = mass of water / (specific gravity of water x 1000)
 = 202 / (1 x 1000)
 = 0.202 m³
- Volume of all in aggregate = [(a-b) - (c + d + e)]
 = [(1 - 0.01) - (0.133 + 0.202)] = 0.99 - 0.335
 = 0.655 m³
- Mass of coarse aggregate = e x Volume of coarse aggregate x specific gravity of coarse aggregate x 1000
 = 0.655 x 0.6567 x 2.795 x 1000 = 1202.23 kg/m³
- Mass of fine aggregate = e x Volume of fine aggregate x specific gravity of fine aggregate x 1000
 = 0.655 x 0.333 x 2.517 x 1000 = 548.995 Kg/m³

MIX PROPORTIONS

Water (litres)	Cement (kg)	Sand (kg)	Coarse aggregate (kg)
202	420.83	549	1202.23
0.48	1	1.30	2.90

3.3 Preparation of concrete cube specimens :

Concrete cubes of size 100 mm x 100mm x 100mm were cast in cube moulds, using the design mix of 1 : 1.30 : 2.90 with water cement ratio of 0.48.

During casting, sodium chloride, amounting to 3.5 percent by weight of cement, was added deliberately, to simulate the effect of sea water. (Reference No.7)

The admixture (Aluminium oxide) contents were varied as 5 percent, 10 percent, 15 percent and 20 percent by weight of cement.

To ensure uniform distribution of salts in concrete, the salts added were first dissolved in distilled water and then mixed with concrete. During casting, moulds were mechanically vibrated.

24 hours after casting, the cubes were de-moulded and cured by complete immersion in distilled water for 7, 14, 28 days.

IV. TESTING PROGRAMME

4.1 Test for compressive strength:

After the curing period of 7, 14 and 28 days was over, the concrete cubes were taken out from curing tank, air dried for 24 hours and then tested for compressive strength using a compression testing machine having a capacity of 2000kN.

The compressive strength data for various periods of curing are reported in the table given below.

Concrete formulation:

Table 1 (a)
CONTROL CUBE MIX © = 1: 1.30: 2.90 with 0.48 w/c ratio

Curing Period (days)	Compressive strength of cubes (N/mm ²)	Average compressive strength of cubes (N/mm ²)
7	Cube 1 = 16.5 Cube 2 = 17.0 Cube 3 = 17.0	16.83
14	Cube 1 = 23.0 Cube 2 = 22.5 Cube 3 = 23.0	22.83
28	Cube 1 = 25.0 Cube 2 = 26.0 Cube 3 = 26.0	25.66

Table 1 (b)
CONTROL CUBE MIX (C) + 3.5% NaCl

Curing Period (days)	Compressive strength of cubes (N/mm ²)	Average compressive strength of cubes (N/mm ²)
7	Cube 1 = 16.0 Cube 2 = 17.0 Cube 3 = 17.0	16.66
14	Cube 1 = 22.5 Cube 2 = 22.5 Cube 3 = 23.0	22.66
28	Cube 1 = 25.0 Cube 2 = 25.0 Cube 3 = 24.0	24.66

Table 1 (c)
CONTROL CUBE MIX (C) + 3.5% NaCl + 5% Al₂O₃

Curing Period (days)	Compressive strength of cubes (N/mm ²)	Average compressive strength of cubes (N/mm ²)
7	Cube 1 = 17.3 Cube 2 = 17.8 Cube 3 = 17.8	17.63
14	Cube 1 = 24.2 Cube 2 = 23.6 Cube 3 = 24.2	24.00
28	Cube 1 = 26.2 Cube 2 = 27.3 Cube 3 = 27.3	26.93

Table 1 (d)

CONTROL CUBE MIX (C) + 3.5% NaCl + 10% Al₂O₃

Curing Period (days)	Compressive strength of cubes (N/mm ²)	Average compressive strength of cubes (N/mm ²)
7	Cube 1 = 18.9 Cube 2 = 19.5 Cube 3 = 19.5	19.30
14	Cube 1 = 26.4 Cube 2 = 25.8 Cube 3 = 26.4	26.20
28	Cube 1 = 28.7 Cube 2 = 29.9 Cube 3 = 29.9	29.50

Table 1 (e)

CONTROL CUBE MIX (C) + 3.5% NaCl + 15% Al₂O₃

Curing Period (days)	Compressive strength of cubes (N/mm ²)	Average compressive strength of cubes (N/mm ²)
7	Cube 1 = 19.8 Cube 2 = 20.4 Cube 3 = 20.4	20.20
14	Cube 1 = 27.6 Cube 2 = 27.0 Cube 3 = 27.6	27.40
28	Cube 1 = 30.0 Cube 2 = 31.2 Cube 3 = 31.2	30.80

Table 1 (f)

CONTROL CUBE MIX (C) + 3.5% NaCl + 20% Al₂O₃

Curing Period (days)	Compressive strength of cubes (N/mm ²)	Average compressive strength of cubes (N/mm ²)
7	Cube 1 = 19.5 Cube 2 = 20.0 Cube 3 = 20.0	19.83
14	Cube 1 = 27.1 Cube 2 = 26.5 Cube 3 = 27.1	26.90
28	Cube 1 = 29.5 Cube 2 = 30.7 Cube 3 = 30.7	30.30

Table 1 (g)

Summary of compressive strength results

Concrete formulations	Average compressive strength (N/mm ²)					
	Curing period in days					
	7 days		14 days		28 days	
	Str eng th	% incr ease over C ₁	St re ng th	% inc rea se over C ₁	Str eng th	% inc rea se over C ₁
C (Control cube mix)	16.83	--	22.83	--	25.66	--
C₁-C + 3.5% NaCl	16.66	--	22.66	--	24.66	--
C₂-C + 3.5% NaCl + 5% Al₂O₃	17.63	5.82	24.00	5.91	26.93	9.20
C₃-C + 3.5% NaCl + 10% Al₂O₃	19.30	15.84	26.20	15.62	29.50	19.62
C₄-C + 3.5% NaCl + 15% Al₂O₃	20.20	21.24	27.40	20.91	30.80	24.89
C₄-C + 3.5% NaCl + 20% Al₂O₃	19.83	19.02	26.90	18.71	30.30	22.87

4.2 Chemical Analysis:

After testing for compressive strength, core samples of concrete (inclusive of fine aggregate and coarse aggregate) collected from 100mm x 100mm x 100mm cubes, were crushed to powder. Then 100 grams of powdered sample was shaken with 200ml of distilled water in a conical flask using a flask shaker, for one hour.

The extract is then filtered through a Whatman filter paper (No.42). The extract prepared from the powdered samples is then analysed for alkalinity and free chloride content.

4.3 Test for Alkalinity:

50cc of filtered solution is taken in 100ml beaker and the alkalinity of the sample is measured in terms of P^H using a standard P^H meter.

The initial P^H for 0 percent admixture: **12.52**

The initial P^H for 15 percent admixture: **12.44**
 Final P^H for 15 percent admixture: **12.43**
 (After 28 days of curing)

Table 1 (h)
Results of alkalinity test

Percentage of admixture	Initial P ^H	Final P ^H (28 days)
0	12.52	-
15	12.44	12.43

4.4 Results and Discussion on Alkalinity:

The alkalinity of crushed concrete samples tested, as indicated by P^H values, showed no significant variation even after 28 days of curing (Refer Table No. 1(h). This indicates that the alkalinity of concrete is not at all affected by adding the admixture.

4.5 Test for Free Chloride Content:

50cc of the filtered solution was taken and the free chloride was estimated by standard silver nitrate solution, using potassium chromate as the Indicator. The amount of chloride present is expressed in terms of parts per million, on the basis of weight of sample taken for analysis.

When enough silver nitrate was added to a sample containing chlorides, all the chloride is precipitated as silver chloride which was a white precipitate. Since all the chloride is precipitated, further addition of even 1 or 2 drops of silver nitrate reacts with the potassium chromate indicator to produce a red precipitate of silver chromate and this change in colour indicates the end point of the titration.

The free chloride contents estimated are reported in the table below.

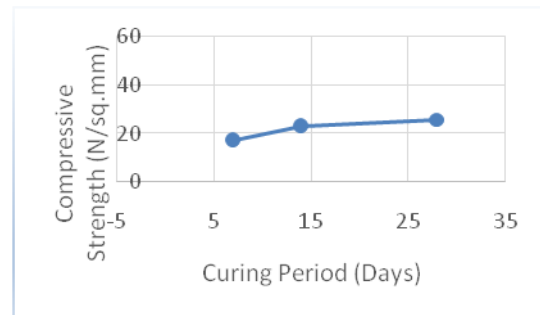
Table 1 (i) Percentage of Chloride in Concrete Cubes

Concrete Formulations	Curing period (days)					
	Curing period in days					
	7 days		14 days		28 days	
	FC ppm	RC percent	FC ppm	RC percent	FC ppm	RC percent
Control (1 : 1.30 : 2.90) 3.5% NaCl	2994	0	2694	0	2131	0
C + 5% Al ₂ O ₃	2892	3.40	2412	10.46	1872	12.15
C + 10% Al ₂ O ₃	2274	24.04	2039	24.31	1603	24.77
C + 15% Al ₂ O ₃	1998	33.26	1728	35.85	1357	36.32
C + 20% Al ₂ O ₃	1901	36.50	1631	39.45	1257	41.01

FC = Free chloride contents
 RC = Reduction chloride level
 C = Control mix of concrete 1 : 1.30 : 2.90 with 0.48 water cement ratio

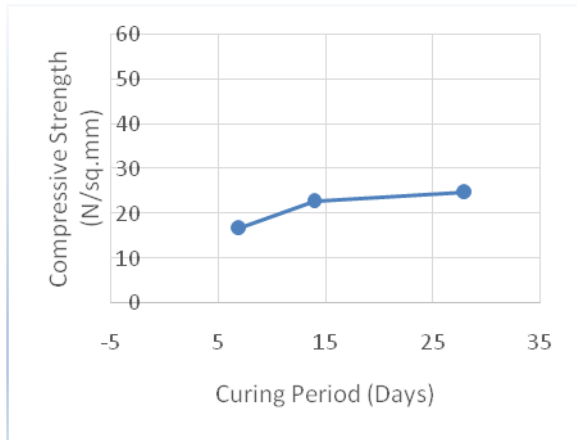
Note: It was observed from above values that Compressive strength is started decreasing at 20% Aluminium Oxide but chloride content shows decrement. Hence 15% of Aluminium Oxide content is taken as optimum.

C = Control cube mix 1: 1.30: 2.90 with 0.48 w/c ratio

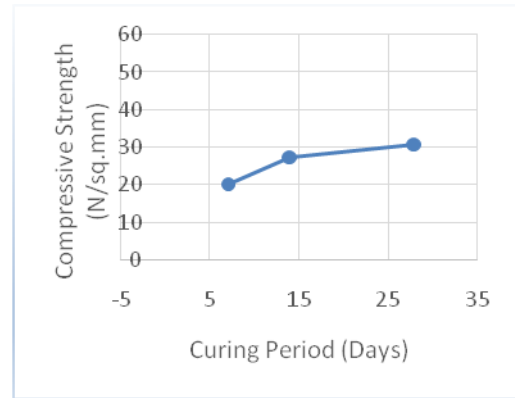


Graph (a)

C1 = C + 3.5% NaCl

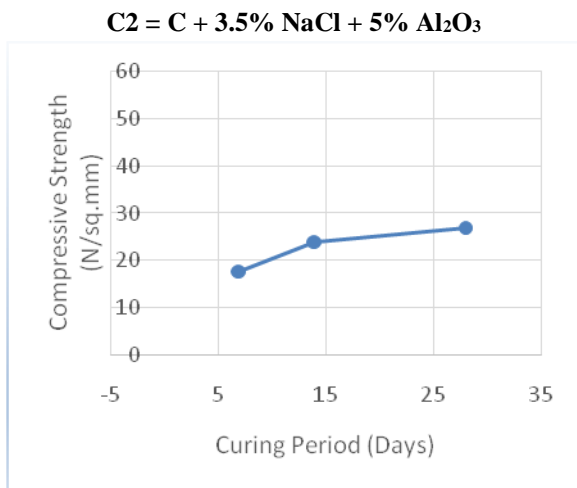


Graph (b)

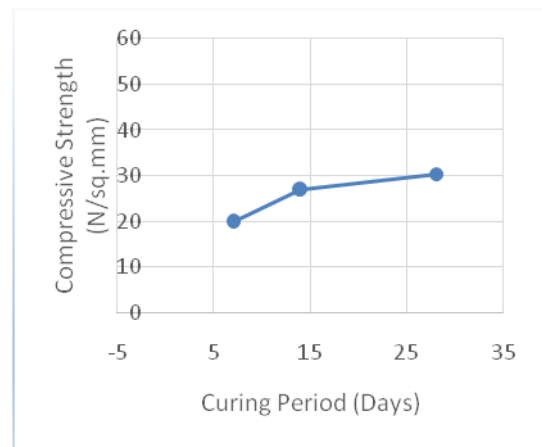


Graph (e)

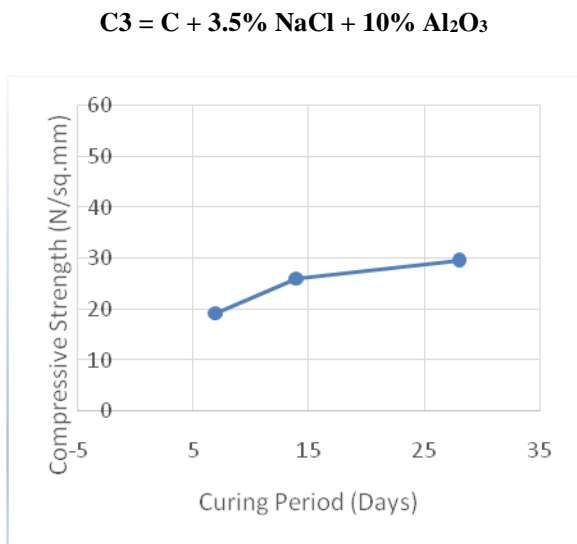
C5 = C + 3.5% NaCl + 20% Al₂O₃



Graph (c)



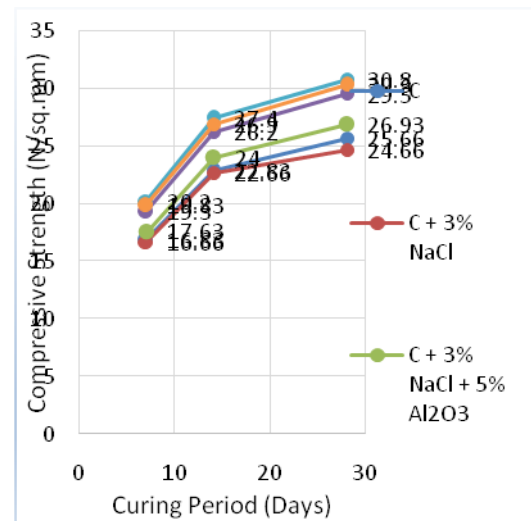
Graph (f)



Graph (d)

C4 = C + 3.5% NaCl + 15% Al₂O₃

Combined Graph of all the Cubes



Graph (g)

V. ANALYSIS OF TEST RESULTS

The compressive strength data for various periods of curing are reported in Table 1 (g). The data clearly indicates that the compressive strength of the concrete increases with aluminium oxide content. The covalent bond developed in the related compounds and complexes, leads to this increase in strength. This strength increase itself indicates the formation of chloro aluminate complexes.

During hydration of Portland cement concrete, calcium silicate contributes most to binding power and strength whereas calcium aluminate contributes to early set and early strength. (Compound of Al_2O_3 and SiO_2 forms one of the best refractory materials.)

Aluminium oxide, as an admixture, performs a dual function. A part of it combines with calcium hydroxide and chloride to form chloroaluminates (chloride scavenger), while the rest of it combines with silicates to form aluminium silicates (strengthening phase).

The free chloride contents estimated are reported in Table 1(i). The free chloride content in control concrete (without admixture) is 2567 ppm and after adding the admixture the free chloride contents are 2467 ppm, 1880 ppm, 1667 ppm for 5 percent, 10 percent and 15 percent added admixture levels respectively.

The percentage reduction in chloride is 35.06 at 15 percent admixture level after 7 days of curing, and 38.24 at 15 percent admixture level after 14 days of curing. A maximum of 39.83 percent chloride was reduced in concrete after 28 days of curing.

VI. CONCLUSIONS

In the present experimental investigation, a method to reduce chloride in concrete has been attempted, using aluminium oxide as an admixture. Salient features of the findings, based on the experimental results of this investigations, as can be observed from Table 1(g,h,i) and graphs 1 to 5, are

1. It was observed that Compressive strength is started decreasing at 20% Aluminium Oxide but chloride content shows decrement.
2. Hence 15% of Aluminium Oxide content is taken as optimum.
3. By adding Aluminium Oxide in the range of 5 to 15 percent by weight of cement, free chloride in concrete can

be reduced considerably as can be observed from Table 1(i).

4. By adding Aluminium Oxide in the range of 5 to 15 percent by weight of cement, 4 to 20 percent increase in compressive strength depending upon the curing time as can be observed from Table 1(g).
5. Neither the compressive strength nor the P^H was adversely affected by this admixture is observed from the Table 1(h).

VII. SCOPE FOR FURTHER STUDY

1. This study was made using 100mm size concrete cube moulds. However, for the same size of the mould, coarse aggregate of size less than 20mm may be used and study may be made, since 20mm size aggregate is more frequently used in construction.
2. Only 3.5% of Sodium Chloride is been used to simulate the Sea Water salt content, hence further study may be made by taking other percentages of Sodium Chloride in Concrete mix.
3. Admixture used here which is Aluminium Oxide is taken of varying percentages 5%, 10%, 15% and 20%. But 15% Aluminium oxide by the weight of cement is considered as optimum since compressive strength is started decreasing at 20%. Hence, a further study may be made using other percentages of Aluminium Oxide which is more than 20% for compressive strength may start increase again.
4. In this study, curing of the test specimen cubes was carried out by submerging the cubes in distilled water. However, curing of concrete structural elements in field practice cannot be done using distilled water which is very expensive to be used in large quantities. Hence, a further study may be made using ordinary portable water for curing.

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