“QUANTIFYING CORROSION OF REINFORCING BARS IN REINFORCED CONCRETE BY IMPRESSED CURRENT METHOD”

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degree

Of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173 234

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DECLARATION

I hereby declare that the work reported in the B.Tech report entitled "**QUANTIFYING CORROSION OF REINFORCING BARS IN REINFORCED CONCRETE BY IMPRESSED CURRENT METHOD** '' submitted **at JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT, SOLAN** is authentic record of my work carried out under the supervision of **Assistant Prof. Dr. Saurav** . I have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work which is being presented in the project title "QUANTIFYING CORROSION OF REINFORCING BARS IN REINFORCED CONCRETE BY IMPRESSED CURRENT METHOD" in partial fulfilment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out **by Shubham Kumar Singh (141673), Vikash Kumar(141677) , Saksham Sethi(141693)** during a period from July 2017 to March 2018 under the supervision of **Assistant Professor Dr. Saurav,** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

Date: - ………………………

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JUIT , Waknaghat	JUIT , Waknaghat	

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ABSTARCT

Cement concrete has clearly emerged as the material of choice for the construction of a large number and variety of structures in the world today [1]. Corrosion of steel reinforcing bar is one of the major causes of premature deterioration reducing service life of reinforced concrete (RC) structures. This increases maintenance and repair cost of the RC structures. In RC structures, corrosion of steel in natural condition is very slow process. Hence generally accelerated corrosion techniques are used in the laboratory to simulate natural corrosion process. An experimental work was carried out to study effect of impressed current on corrosion of steel reinforcing bar in concrete. In this experiment, three different voltages are used and is impressed on reinforced bar in concrete. Cylindrical specimen of 150mm diameter and 300mm height reinforced with bars o diameter 10mm, 12mm, 16mm and beams with different covers of bars are tested at 3% , 4% and 5% NaCl concentration are tested at different voltages and number of days for the start of crack propagation is noted , later the bar is retrieved and the mass of rust is obtained and the results are compared with those obtained theoretically from Faraday's law.

CHAPTER 1

INTRODUCTION

1.1 General

Corrosion is a naturally occuring mechanism, which converts a refined metal to a more chemically-stable form, such as its oxide, hydroxide, or sulphide.

In overall sense under normal condition various metals and their naturally developed compounds have certain stable states. The naturally occurring pure metals like gold and platinum are stable on their own and are called "noble" metals. Iron (Fe) on the other hand is not naturally stable and is able to attain stability in the form of different oxides(FeO. Fe_2O_3, Fe_3O_4 etc.) which is described by the energy level of these materials. The oxides have lower energy level and to separate and obtain iron and steel, energy is supplied to them in the manufacturing process. The metals extracted tend to move back to lower energy levels i.e to stable state. This is the basic reason behind corrosion.

Due to the corrosion of steel in reinforced concrete, a large reduction in the strength parameters like flexural and bond strength has been observed which ultimately lead to reduction in load carrying capacity of reinforced concrete element which eventually results in high maintenance of the structures. Thus, corrosion of steel is a critical phenomenon and it needs to be addressed and researched widely.

1.2Corrosion of steel

1.2.1 Mechanism of corrosion in reinforced concrete

Corrosion of reinforcing steel in concrete is a process termed as electrochemical process. Difference in electrical potential along the steel reinforcement in concrete leads to a generation of an electrochemical cell setup. In the steel bar, one part is designated as anode and another part becomes cathode and the pore water in the hardened cement paste acts as the electrolyte resulting in the generation of a liquid medium i.e. a complex electrolyte. Fig.1.1 shows the overall exchanging of electrons between anode and cathode

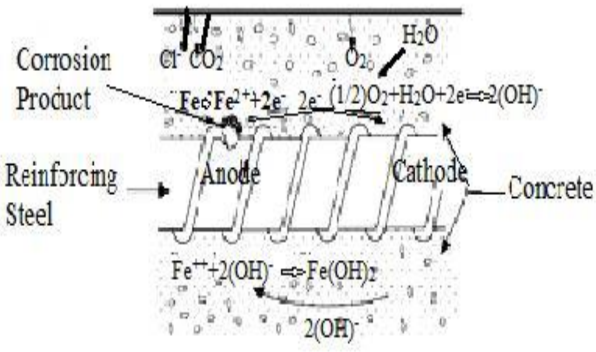

Fig. 1.1 Demonstration of corrosion of steel in concrete [3]

The ferrous ions Fe^{+2}generated at the anode enters into the solution while the electrons carrying negative charge pass through the steel into cathode where they are imbibed in the electrolyte and reacts with oxygen and water to produce hydroxyl ions $(OH)^{-}$. These pass through the pore solution forming ferric oxide which at the later stages of corrosion is converted to rust.

In the cases where concrete is arid or the percentage of relative humidity is below 60 percent, scarcity of water do not promote the initiation of corrosion. There is no corrosion taking place when the concrete is completely inundant, which does not allow the entrainment of air. It is investigated that the optimum limited humidity for corrosion is 70 to 80 percent.

The products obtained after corrosion occupies volume about six times the volume of steel as per the stage of oxidation reached. Fig 1.2 shows the increase in volume of steel depending upon the oxidation.

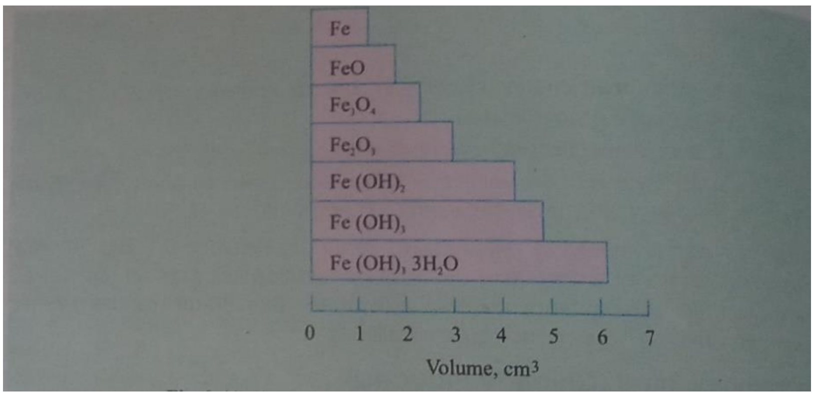

Fig 1.2 Depicting that metallic iron on reaching the desired oxidation state can increase more than six time in volume

1.2.2Reactions occurring at anode and cathode

At the anode:

$Fe \rightarrow Fe^{++} + 2e^-$ (1)

$Fe^{++} + 2(OH)^- \rightarrow Fe(OH)_2$ (2)

$4Fe(OH)_2 + 2H_2O + O2 \rightarrow 4Fe(OH)_3$ (3)

At the cathode:

$4e^- + O_2 + H_2O \rightarrow 4(OH)^-$ (4)

1.3 Factors affecting reinforcement corrosion

1.3.1 Effect of carbonation and entry of gaseous pollutants

Carbonation and the entrainment of gaseous pollutants (acidic) such as SO_2 and NO_2. The drop in pH to acertain level evince initiation of corrosion, loss of resistance of concrete in preventing rebar corrosion and catastrophic corrosion.

1.3.2 Effect of aggressive anions

Presence of chloride in concrete as Acid soluble chloride bounded chemically with hydration products of cement and freely or chloride that are water soluble within the pore solution that acts as the electrolyte. Generally, the corrosion process is influenced by the amount of free chloride ions (Cl^-)[6]. It is detected that the corrosion rate is directly proportional to the increase in chloride content. However, the pH is not affected with change in chloride content of concrete.

1.3.3 Effect of Bacterial action

Aerobic bacteria may generate a differential aeration cell which will eventually lead to corrosion. In concrete, iron sulphides produced by anaerobic bacteria allows the corrosion to occur even in shortage or unavailability of oxygen. Reduction in cover by the bacteria is done by disintegrating cementitious material [7].

1.3.4 Effect of w/c ratio

Factors like strength, permeability and durability of concrete are influenced by the w/c ratio however the rate of corrosion is not affected , though permeability affects corrosion . The threshold value of chloride's penetration depth increases directly with an increase in the w/c ratio [8]. A linear increasing relation has been observed between Carbonation depth and w/c ratio [9].

1.3.5 Effect of cover over reinforcing steel

Low thickness of cover promotes corrosion has been stated by numerous researchers. The cover provided has a huge impact on corrosion of bar due to chloride or carbonate ions penetration [10]. This effect of corrosion is noticed between the casting to the time where depassivation of bar is reached and the corrosion is initiated .Corrosion after the initiation is independent of thickness of cover provided.[11].

1.4 Corrosion Control

Case studies has shown that collapsing of structures on the account of embedded steel reinforcement corrosion accounts to about 40 percent. Therefore prevention of steel reinforcement from corrosion is subject of utmost priority.

Corrosion control can be easily ensured by the usage of concrete assuring the good quality which can be accessed through proper practises of construction. In particular involving the lowest allowed w/c ratio keeping in mind the workability. Adding superplasticizers can decrease the w/c ratio to produce a stiff concrete.

For proper mix design, use of defined and good quality and amount of cement for varied exposure conditions is to be adopted. It was investigated that high durability can't be achieved with lower w/c ratio associated with low permeability . Silica fumes adds to the overall improvements in concrete which helps in reducing corrosion of steel reinforcement. Hence protection of steel reinforcement from corrosion is enhanced by improving the micro structure of the hydrated cement paste. The intrinsic long term drying shrinkage and microcracks in concrete, the problem becomes more serious. This demand certain other measures to control the corrosion of steel reinforcement.

1.5 Methods of controlling corrosion

1.5.1 By Metallurgy

Steel can be made more safe from corrosion by changing its structure through exhaustive metallurgical procedures. Diverse techniques, for example, quick cooling of the hot bars by arrangement of water planes or by keeping the hot steel bars for a brief span in water shower, and by such different process the mechanical properties and corrosion protection property of steel can be progressed.

1.5.2 Corrosion inhibitors

Corrosion can be reduced by chemical method by using specific corrosion inhibiting materials such as nitrites, phosphates, benzoates etc. Of the available materials, the most widely used admixture is derived from calcium nitrite. It is mixed during the preparation of concrete. In the highly alkaline environment of concrete, the steel is ensured by a depositing a layer of ferric oxide on the surface of steel.

1.5.3 Coatings to reinforcement

The objective of galavanizing a steel bar is to obtain a durable barrier to aggressive materials, such as chlorides. The coating should be robust to withstand fabrication of reinforcement cage and pouring of concrete and compaction by vibrating needle. Simple cement slurry layer coating is a cheap method for transient protection against rusting of reinforcement .

1.5.4 Cathodic Protection

Cathodic protection is one of the viable, understood and broadly utilized strategies for counteractive action of corrosion in solid structures in developed nations. Because of high cost and long haul checking required for this strategy, it isn't particularly utilized in India.

The cathodic protection contains use of impressed current to an electrode laid on concrete above steel support. This electrode works as anode and the steel reinforcement which is associated with the negative terminal of DC source acts as cathode. In this procedure. the external anode is subjected to corrosion and the cathodic reinforcement is saved against corrosion and is subsequently named as "Cathodic Protection".

In this procedure, the negative chloride ions which are primary cause for the harm of passivating film , are dragged away from the region of steel towards the anode where chlorine gas is released. The surrounding around the steel returns to alkaline state by which the steel is protected.

1.5.5 Coatings to concrete

In the past, it was trusted that concrete without any assistance was a sturdy material which require no assurance or protection. This conviction is no more hold great especially because of natural contamination and pollution and deterioration of ground water. Not withstanding the covering of reinforcement by proper material, a surface covering to the solid part is given to enhance the durability . The covering fills the double need of protection and design. Epoxy based covering material isn't impervious to UV beams when presented to daylight and furthermore it isn't adaptable. While the covering material in view of acrylic polymer is impervious to UV beams of sun and is adaptable.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Experimental investigation of different research papers were studied to analyse the different methods to stimulate corrosion of steel reinforcement in concrete. Research gaps in different papers were studied to work out the process of initiating corrosion in concrete by impressed current method . Various other methods like Finite element method relates the experimentally calculated mass of rust to the theoretically calculated mass of result using faraday's law.

2.2 Research Papers

2.2.1 Title: Effectiveness of Impressed Current Technique to Simulate Corrosion of Steel Reinforcement in Concrete by Tamer A. El Maaddawy and Khaled A. Soudki

Corrosion of steel was fastened in concrete structures by varying the impressed current density. The investigation assessed the concrete side strain conduct, the split width, and uniform consumption of steel under various levels of corrosion rates were studied to calculate mass losses. The final crack pattern was independent of current density. For all examples tested , the splits because of corrosion were parallel to the steel bars paying little regard to the level of current density used to instigate the corrosion .

2.2.2 Title: Corrosion inhibitors for chlorides induced corrosion in reinforced concrete structures by M. Ormellese, M. Berra, F. Bolzoni, T. Pastore (2006)

This paper investigates the effectiveness of three organic commercial inhibitors in preventing carbon steel chlorides induced corrosion in concrete Inhibitors were added to the concrete mixture in dosage suggested by the manufacturers. Chlorides were included in concrete blend or entered from outside by "ponding" cycles with a 3.5% sodium chloride arrangement. The viability of the inhibitors has been assessed by examining rebar corrosion by keeping long time monitoring of the bars and by rebar visual review following three years tests. Likewise arrangement tests were performed so as to confirm the viability of inhibition.

2.2.3 Title: Experimental and Numerical Investigation of Corrosion-Induced Cover Cracking in Reinforced Concrete Structures by: Dimitri V. Val; Leonid Chernin ; and Mark G. Stewart

In the paper crack initiation and propagation in RC structures due to corrosion of reinforcing steel have been investigated using experimental and numerical methods. At first, the FE display has been quickly portrayed and afterward confirmed against accessible exploratory information. The model has been utilized to appraise the measure of corrosion by

products infiltrating into concrete pores and splits generated in concrete and accordingly, not bringing about any fresh crack to propagate . As indicated by the outcomes, the measure of corrosion products infiltrating into the solid pores previously before cracks initiation and propagation is bigger than that acquired by different scientists. Besides, it is evident that this ought to rely upon the porosity of cement and along these lines on the water/cement proportion and the concrete compressive resistance though not justified by the outcomes acquired from this paper. The outcomes acquired likewise demonstrate that corrosion items don't completely possess the spaces induced between the cracks prompted in concrete instantly after the start. The spaces induced in cracks are filled slowly with time and the thicker the concrete cover the more it will take to fill the spaces produced between the breaks

2.2.4 Title: Reinforcement corrosion in concrete structures, its monitoring and service life prediction by Shamsad Ahmad, (2003)

In this paper, an audit is exhibited on the system of reinforcements corrosion, procedures used to investigate reinforcement corrosion and strategies that are used for the forecast of service life left of the structures. The examination of the causes and degree of corrosion carried out were assessed using different electrochemical methods. Judgement of the remaining service life of a corroded RC structure were estimated with the assistance of empirically derived models and test strategies. The data about the condition of reinforcement is acquired in terms of measurement parameters, namely half-cell potential, concrete resistivity and corrosion current density

2.2.5 Title: Electrochemical behaviour of steel reinforced concrete during accelerated corrosion testing by S.A. Austin, R. Lyons, M.J. Ing

The logical justification for quickening corrosion using an impressed current is strong, drastically shortening the starting period required for depassivation from years to days and settling the required rate of corrosion without adjusting the truth of the corrosion products framed. Following conclusion can be gotten from this analysis:

- It is confirmed that the impressed current technique is a viable and rapid strategy for quickening chloride induced corrosion.
- While accounting for oxygen evolution and passivity, it was shown that Faraday's law altogether enhance the relationship amongst hypothetical and gravimetrical mass loss.
- In absence of chloride ions, oxygen is evolved from the applied current.
- It was observed that the thickness of the concrete has a greater influence than the compressive strength of concrete on the time required for chlorides to reach the reinforcement placed.

2.2.6 Title: Corrosion Measurement Techniques in Steel Reinforced Concrete by A. Poursaee, (2011)

This investigation assessed distinctive corrosion measurement systems all together to determine the most exact strategies for estimating the corrosion rate of steel bars in reinforced steel concrete. RC specimens were casted and presented to salt solution, and the corrosion activity of the bars was explored considerably through cell potential. The outcomes acquired by the strategies were then contrasted and compared with the real mass loss of the steel bars because of corrosion (gravimetry test) and it demonstrates that procedures in light of applying potential are more dependable estimating systems contrasted with those based on applying current

.2.2.7 Title: Effect of impressed current on corrosion of Reinforcing bar in reinforced concrete by: Nabeel Shaikh, Sheetal Sahare

The impact of differing the impressed current level to quicken steel corrosion in solid structures was tentatively examined. The examination evaluate the solid break design, time versus crack, and the mass losses occurred because of fastened corrosion upto advancement of first noticeable crack on the surface of solid example. Following conclusion can be withdrawn from this analysis:

- Crack pattern observed is independent of the voltage level connected. For all test examples, the cracks because of production of corrosion products were parallel to the steel bars embedded in concrete indifferent to the voltage level connected to cause corrosion.

- Time taken to manifest the first visible crack on the concrete surface is directly proportional to the C/D ratio for same voltage applied and inversely proportional to the voltage applied for the same C/D ratio.
- Mass losses were decreased with increment in C/D proportion for same voltage connected upto the manifestation of first visible crack on surface.
- There is decrease in mass loss with increasing voltage for same C/D ratio.
-

2.2.8 Title: A study on corrosion of reinforcement in concrete and effect of inhibitor on service life of RCC by V. Kumar, Ramesh Singh, M. A. Quraishi, (2013)

Study uncovered that utilization of 3% Calcium Palmitate resulted in the reduction of compressive strength of the concrete by 41% but improve the restraint limit of strengthened cement impressively expanding the administration life of RC structure almost ten times. Same administration life of a RC structure might be achieved by utilizing 1.5% Calcium Palmitate in blend with 3% Calcium Nitrite , in such case 25% reduction in compressive strength was observed. The service life predicted here depends on the test information of a shorter length with no application of load.

2.2.9 Title: Comparative Study on Various Methods Used for Corrosion Protection of Rebar in Concrete by Sravana Babu Parvatareddy, G. Ganesh Naidu, (2017)

This paper tentatively analyzes the five usually utilized techniques for corrosion protection of bar embedded inside the concrete which are; high strength concrete, utilization of inhibitors , solid surface coating, bar coating and cathodic protection. Toward the finish of destructive corrosion, pullout test is done on all specimens to calculate bond strength. After the pullout test, mass loss in the rebar is evaluated. Every one of these parameters are contrasted and compared with the control sample which is unprotected and the relative favourable circumstances and detriments of all the methods have been examined.

2.2.10 Title: Analysis of half-cell potential measurement for corrosion of reinforced concrete by Veerachai Leelalerkiet, Je-Woon Kyung, Masayasu Ohtsu, Masaru Yokota, (2004)

Non-ruinous assessment strategies by the half-cell potential estimation are connected to calculate the consumption of fortifying steel-bars in concrete under cyclic conditions of wet and dry . The three-dimensional boundary element technique (BEM) is connected to think about the potential distributions and current streams of bar. At that point, the Inverse boundary element method (IBEM) is connected to experimental results to distinguish the corrosion states. The impact of a void on the potential dispersion and current stream flow is likewise researched. Results demonstrate that the half-cell potential estimation is hardly effective contrasted and explanatory consequences of potential appropriation and current flow . It is exhibited that outcomes by IBEM examination identify corroded territories clearly.

2.3 RESEARCH GAPS

- Dependency of corrosion on the varying cover provided to rebars.
- Dependency of corrosion on the type of bars used (plain bars and deformed bars).
- Final estimation of strength of the specimen before and after corrosion.
- Dependency of corrosion on the varying l/d ratios of different cylindrical specimens.
- Effect of corrosion on ductility of reinforcing bars.

2.4 RESEARCH OBJECTIVES

- Observing corrosion of reinforcement (deformed bars of 3 different dia.) embedded in cylindrical specimens of concrete at same concentration of NaCl by calculating the mass of rust.
- Observing corrosion of reinforcement after application of corrosion inhibitor (Nerolac Metal Oxide i.e. primer coater) on deformed bars and comparing the results.

- Observing corrosion of deformed bars separately dipped in NaCl solution with and without application of corrosion inhibitor.

CHAPTER 3

EXPERIMENTAL ANALYSIS

3.1 GENERAL

Discussing about all the materials and instruments used in the preparation of the setup and the casting of specimen . Properties of the materials and the basic information of the instruments and their usage has been clearly mentioned . Different tests performed on the materials are mentioned along with the results like specific gravity test , water absorption test , sieve analysis of fine and coarse aggregate etc to obtain the Mix design of M20.

3.2 Materials used

3.2.1 Cement

The historical backdrop of establishing material is as old as the historical backdrop of building development. It is trusted that the early Egyptians for the most part utilized establishing materials. The examinations of L.J.Vicat drove him to set up a counterfeit pressure driven line by calcining a cozy blend of limestone and dirt. This procedure might be viewed as the main learning to make of Portland concrete.

Earlier, concrete was utilized for producing mortar as it were. Afterward, the utilization of bond was reached out for producing concrete. As the utilization of Portland bond was expanded for making solid, engineers called for reliably higher standard material for use in significant works.

There are many types of cement of which mainly Ordinary Portland cement(OPC) and Portland Pozzolana cement(PPC) are used.

3.2.1.1 Ordinary Portland cement

OPC is by a long shot the most vital sort of bond. Preceding 1987, there was just a single review of OPC which was administered by IS: 269-1976. The OPC was characterized into three evaluations, to be specific 33grade, 43grade, and 53grade relying on the quality of bond at 28 days. The make of OPC is diminishing everywhere throughout the world in perspective of the ubiquity of mixed concrete because of lower vitality utilization, natural contamination, monetary and other specialized reasons.

3.2.1.2 Portland Pozzolana cement

The origin of Pozzolanic material goes back to romans time. PPC is made by granulating of OPC clinker with 10%-25% of pozzolanic material. A pozzolanic material is vitally a siliceous or aluminous material which while in itself containing no cementitious properties, which will, in finely partitioned form and in the accessibility of water, react to calcium hydroxide, freed in process of hydration at typical temperature, to form mixes involving cementitious properties.

3.2.2 Aggregates

Aggregates form an important part in concrete. They give body to the concrete, diminish shrinkage and impact economy. Prior, aggregates were considered as chemically inert materials but now it has been perceived that a portion of the aggregates are synthetically dynamic and furthermore that specific aggregates show chemical bond at the interface of aggregates and paste. The indispensable truth that the aggregates involve 70– 80 percent of the volume of cement, their effect on different qualities and properties of cement is without a doubt impressive. Aggregates can likewise be grouped based on the size of the aggregates as coarse and fine aggregates.

3.2.2.1 Coarse Aggregates

Coarse aggregates are common aggregate materials start from bed rocks. There are three sorts of rocks specifically, volcanic, sedimentary and transformative. These characterizations depend on the mode of arrangement of rocks. It might be reviewed that volcanic rocks are shaped by the cooling of liquid magma at the surface of the peak (trap and basalt) or, deep underneath the peak (stone). The sedimentary rocks are shaped initially underneath the ocean and then lifted up. Metamorphic rocks are originally either molten or sedimentary rocks which are in this way transformed because of outrageous warmth and weight. The concrete making properties of aggregates are influenced to some degree based on geographical development of the parent rocks together with the resulting procedures of weathering and modification.Within the main rock groups, the quality of aggregate may differ to a very great extent due to changes in the structure and texture of the main parent rock. The size of aggregates bigger than 4.75mm is considered as coarse aggregates.

3.2.2.2 Fine Aggregates

The aggregates whose size is less than 4.75mm are considered as fine aggregates. Fine aggregates mainly comprises of sand. The voids formed by the coarse aggregates and cement in the concrete mixtures are filled by these aggregates.

3.2.3 Reinforcements

Reinforcements are steel bars. Its main advantages are strength, speed of erection, prefabrication and demountability. Its principle favourable circumstances are quality, speed of erection, construction and demountability. Auxiliary steel is utilized as a part of load bearing edges in structures and as members in trusses and space frame. However, steel requires protection from fire and corrosion. In this project, the reinforcement used are of diameter 12mm, 16mm and 20mm.

Fig. 3.2 Steel bars

3.3 Instruments

3.3.1 Power supply

Power supply was used to supply the different voltages required during the experiment. Positive terminal of the device was attached to the bar and the negative terminal was attached to the galvanized iron sheet.

Fig. 3.2 Power Supply

3.3.2 Multimeter

A Multimeter is a device used to measure voltage, current and resistance. It is also known as Volt-Ohm meter. It is an electronic measuring instrument that is used to measure several functions as stated above. There are two types of Multimeter i.e analog Multimeter and digital multimeter. Analog multimeter uses a microammeter consisting of a pointer to display readings. Digital multimeters have numeric display to display readings. It also show graphical bar representing the measured value.

Fig. 3.3 Multimeter

3.4 Tests performed for mix design

3.4.1 ABSORPTION TEST OF AGGREGATE

A portion of the total aggregates collected are permeable and absorptive. Porosity and absorption will influence the w/c proportion and subsequently the workability of cement. The water absorption of aggregate is calculated by estimating the change in weight of a sample(oven dried) when inundated in water for 24 hours. The proportion of the increase in weight to the weight of the dry sample in percentage is known as absorption of aggregate. Water is consumed by the aggregate which influences the workability and final volume of cement. The rate and measure of absorption within a period is equivalent to the final arrangement of the cement may be a huge factor instead of the 24 hours absorption of the total aggregates.

A sample of 2000g was used in this test. The apparatus used were wire basket, water tight compartment for suspending the wire basket, drying cloth, tray, air tight compartment of a capacity similar to basket and oven.

Table 3.1 Water absorption

Sample weight	2000.0g
Saturated surface dried weight (A)	1.956 kg
Oven dried weight (B)	1.926 kg

Water absorption = (A-B/B)×100 = 1.56 %

3.4.2 SPECIFIC GRAVITY OF AGGREGATE

The specific gravity of an aggregate is a measure of quality or nature of the material. Aggregates with low specific gravity are weaker in comparison to that of higher specific gravity values. In concrete, specific gravity is utilized for design computations of concrete blends. With the specific gravity of every constituent known, its weight can be changed over into volume and henceforth a hypothetical yield of cement per unit volume can be computed. Specific gravity of aggregate is additionally required in ascertaining the compacting factor regarding the workability estimations. Specific gravity of aggregate is required to be considered when we manage light and heavy weight concrete. Normal specific gravity of the aggregates differs from 2.6 to 2.8.

Around 2 kg of total sample is washed altogether to expel fines, depleted and set in wire basket and submerged in refined water at a temperature between 22-32º C.

Table 3.2 Specific Gravity of aggregates

Weightof saturated aggregate suspended in water with basket (W1)	1.74kg
Weight of basket in water (W2)	0.48kg
Weight of surface dry aggregate in air (W3)	1.956kg
Oven dry aggregate weight	1.926kg

SPECIFIC GRAVITY OF AGGREGATE = $W_3 / (W_3 - (W_1 - W_2))$ = 2.81

Fig.3.4 Water absorption and specific gravity test of aggregate

3.4.3 Sieve analysis of sand

In the BS and ASTM gauges, the sieve sizes are given as far as the number of openings per inch. The square of the quantity of sieve is equivalent to the number of openings per square inch. Sieving is performed by organizing the different sieves one over the other in the order of their opening sizes. The biggest opening sieve being kept at the top and the smallest opening sieve at the base. A collector is kept at the base and a cover is kept at the highest point of the entire assembly. Shaking periods depends on the shape and the number of particles. Atleast 10 minutes of shaking is desirable for sand particles.

Weight of sample = 1000g

Table 3.3 Sieve analysis of sand

Sieve	Weight retained on each sieve (g)	Weight retained on each sieve (%)	Cumulative % retained	Passing through Weight (g)	Passing through (%)
40mm	Nil	0.0	0.0	987.0	100.0
20mm	Nil	0.0	0.0	987.0	100.0
10mm	Nil	0.0	0.0	987.0	100.0
4.75mm	6.0	0.61	0.61	981.0	99.390
2.36mm	8.50	0.860	1.47	972.50	98.5310
1.18mm	9.50	0.961	2.431	963.0	97.560
600µ	12.70	1.285	3.718	950.30	96.280
300µ	80.10	8.117	11.831	870.20	88.1670
150µ	775.30	78.56	90.3820	94.90	9.6150
Passing 150µ	94.0	9.524			
Total	986.11				

Zone of the sand is selected from the table in **(IS: 383-1970)**[12] by comparing the percentage passing for 600µ with the percentage given in the next table.

Table 3.4 IS: 383-1970

IS Sieve	Equivalent BS sieve	Percentage passing for			
		Zone 1	Zone 2	Zone 3	Zone 4
10 mm	3/8 -in	100	100	100	100
4.75 mm	3/16 - in	90-100	90-100	90-100	95-100
2.36 mm	No.7	60-95	75-100	85-100	95-100
1.18 mm	No.14	30-70	55-90	75-100	90-100
600 micron	No.25	15-34	35-59	60-79	80-100
300 micron	No.52	5-20	8-30	12-40	15-50
150 micron	No.100	0-10	0-10	0-10	0-15

ZONE OF THE SAND OBTAINED = **ZONE 4**

Fig. 3.5 Sieve analysis of sand

3.4.4 SPECIFIC GRAVITY OF SAND

The objective of this test is to determine the specific gravity of soil fraction passing 4.75mm IS sieve by pycnometer. Particularly specific gravity is characterized as the ratio of the weight of a given volume of soil solids at offered temperature to the heaviness of an equal volume of refined water at that.temperature , the two weights being taken in air.

Table 3.5 specific gravity of sand

Weight of bottle (W1)	644.30gm
Weight of bottle with soil (W2)	844.30gm
Weight of bottle, soil and water (W3)	1545.70gm
Weight of bottle and water (W4)	1416.20gm

Specific Gravity of sand=(W2-W1)/((W4-W1)-(W3-W2))

=2.84

Fig.3.6.specific gravity of sand

3.5 MIX DESIGN

3.4.1 DESIGN STIPULATIONS

Characteristic compressive strength required	20.0 N/mm^2
Maximum size of aggregate	20.0 mm angular
Compaction factor	0.90
Degree of quality control	Good
Exposure	Mild

3.4.2 TEST DATA FOR MATERIALS

Cement	PPC
Specific gravity of cement	3.15
Specific gravity of coarse aggregate	2.81
Specific gravity of fine aggregate	2.84
Water absorption of coarse aggregate	1.5%
Water absorption of fine aggregate	1%
Water to cement ratio	0.50

Table 3.6 final mix design

Water	Cement	Fine aggregate	Coarse aggregate
191.61 kg/m^3	383.161 kg/m^3	587.030 kg/m^3	1292.821 kg/m^3

Final Mix Design- 1:1.532:3.37

Volume of concrete required for 3 cylindrical specimen	0.0159 m^3
Mass of cement	6.2 kg
Mass of fine aggregate	9.5 kg
Mass of coarse aggregate	21 kg
Volume of water	3.2 litre

3.6 SPECIMEN

- Cylindrical specimen of M20 characteristic strength were casted with bars held concentrically of diameter 12mm, 16mm and 20mm.
- Size of the cylindrical mould used is of 30cm height and 15cm diameter.
- The length of the bar embedded is 47cm of all the three diameter bars .

Fig.3.7 Casted Specimen

- After 24 hours, specimens were demoulded and kept for curing in water tank at room temperature.

Fig. 3.8 Remoulded Specimen

CHAPTER 4

EXPERIMENTAL SETUP AND RESULTS

4.1 GENERAL

The setup has been discussed with the complete procedure followed. The various preparations done before the placing of specimen in NaCl solution has been discussed and shown alongside with the various images of the setup during the different stages of the corrosion. A voltage supplier was used to provide the required voltage. The test was performed on inhibitor coated bars and simple bars both placed individually and thereafter embedded in concrete so as to compare the results .

4.2 ACCELERATED CORROSION TECHNOQUE (IMPRESSED CURRENT METHOD)

In this technique, a consistent voltage is supplied to the steel bar inserted in concrete and current from the reinforcing steel to counter conductor is estimated periodically, a pointy ascend in current is demonstrative of the beginning of corrosion. The anode is that the sample to be tested and cathode is a galvanized iron sheet bar. This potential unit is adequate for a noteworthy adjustment in current level. The level of corrosion intensity is measured by Faraday law. Fig. 4.1 demonstrates a general read of the specimens exposed to accelerated corrosion.

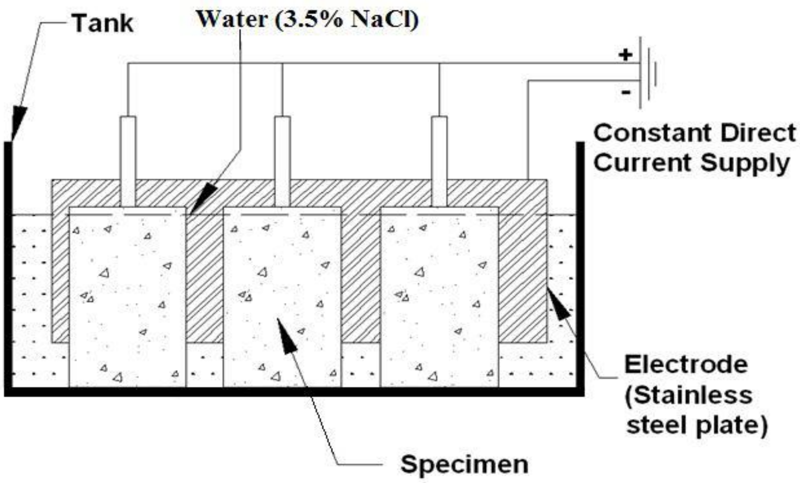

Fig.4.1: Schematic view of accelerated corrosion technique

4.3CORROSION ACCLERATION

After accelerated curing for 7 days, the sample was immersed in 3% NaCl solution for 24 hours before putting in solution for accelerated corrosion. The concrete samples were inundated 25mm beneath the highest point of concrete put in tank. After a day, samples were set for accelerated corrosion process in a similar tank by applying consistent voltages of 15 volts till the occurrence of first split on the outer surface of a specimen. The current was provided by DC power supply at a steady voltage with an internal ammeter to measure the current. The arrangement was changed after each 3 successive days. The direction of the current is so that the reinforcing steel worked as an anode and a passive iron sheet placed in the tank filled with sodium chloride solution act as a cathode.

Fig.4.2 Specimen kept in NaCl solution for 24 hours

4.4 EXPERIMENTAL SETUP

4.4.1 Experimental setup of simple bar embedded in concrete immersed in NaCl solution

Fig.4.3 Experimental setup on 1st day

- Volume of water in the container = 65 litre
- Amount of NaCl added = 2 kg (3%)
- Electrode used - Galvanised Iron Sheet to act as Cathode
- Setup is connected to a voltage supplier at 15 Volts.
- Positive terminal is attached to the bar and negative terminal to the Galvanised Iron sheet.

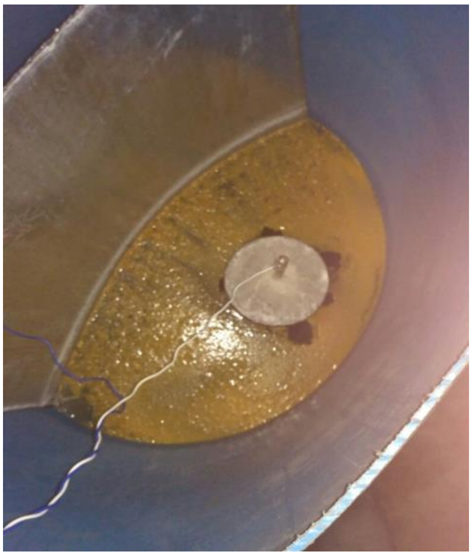

Fig.4.4 Experimental setup in later stages

- After 24 hours, colour of the solution changed to greenish colour indicating the onset of corrosion and the change in the value of current from 0.71amp to 0.28amp.
- The solution in the container was changed after every 3 days and the time for the initiation of cracks was noted.
- The layer of rust greenish in colour kept on increasing in thickness with the passage of days .

4.4.2 Crack propagation pattern observed

Fig.4.4 Crack Propagation of Sample

Expansion of corrosion products were monitored to study the crack pattern for each specimen applied for constant voltages with bars of different diameters. In general, two types of crack patterns were observed in the specimens. Type 1 cracking where a surface crack parallel to the reinforcing bar on the outer surface of the specimen was observed . In Type 2 cracking, crack on the surface perpendicular to the protruded bar was observed shown in the Fig.4.4However no relation has been seen between the voltage applied and the pattern of crack observed in the specimens .

4.4.3 Measurement and Quantification of Corrosion

- After the occurrence of first surface crack on specimens, the steel bars are taken out of the specimens. The rust formed is then cleaned by stiff metal brush and then weighed to determine the actual mass loss of the steel reinforcing bars.
- The average loss of mass of bars at same voltages is calculated for 12mm, 16mm and 20mm dia. bars separately.

Fig. 4.5 Retrieved bars

4.4.4 Experimental setup of simple bar immersed in NaCl solution

Fig. 4.6 Experimental setup of simple bar dipped in NaCl solution

- Simple bars of three different diameters (12mm,16mm,20mm) were immersed in 3% NaCl solution .
- Volume of Solution = 60 litres
- Electrode used - Galvanised Iron Sheet to act as Cathode
- Setup is connected to a voltage supplier at 15 Volts.
- Positive terminal is attached to the bar and negative terminal to the Galvanised Iron sheet.

Fig. 4.7 Setup after 48 hours

- A Thick brown layer of rust was observed after 3 days of passing the current that lead to the deterioration of the bar immersed resulting in weight loss of the bar

4.4.5 Experimental setup of inhibitor coated bar immersedin NaCl

Fig.4.8 Setup for inhibitor coated bar

- Volume of water in the container = 60 litre
- Amount of NaCl added = 2 kg (3%)

- Electrode used - Galvanised Iron Sheet to act as Cathode
- Setup is connected to a voltage supplier at 15 Volts.
- Positive terminal is attached to the bar and negative terminal to the Galvanised Iron sheet.

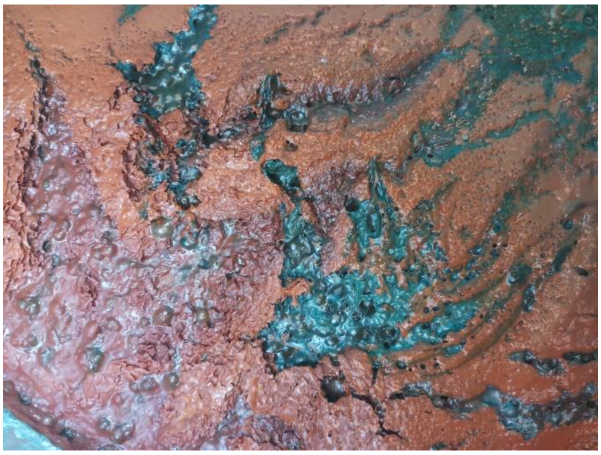

Fig 4.9 Setup after 36 hours

- A Thick brown layer of rust was observed after 3 days of passing the current that lead to the deterioration of the bar immersed resulting in weight loss of the bar.

4.4.6 Experimental setup of coated bar embedded in concrete immersed in NaCl solution

Fig 4.10 Experimental step up of coated bar embedded in concrete

- Volume of water in the container = 65 litre
- Amount of NaCl added = 2 kg (3%)
- Electrode used - Galvanised Iron Sheet to act as Cathode.
- Setup is connected to a voltage supplier at 15 Volts.
- Positive terminal is attached to the bar and negative terminal to the Galvanised Iron sheet.

Fig 4.11 Experimental setup of coated bar embedded in concrete after few days

- After some days, colour of the solution changed to reddish colour indicating the onset of corrosion and the change in the value of current from 0.51amp to 0.04amp.
- The solution in the container is changed after every 3 days and the time for the initiation of cracks is noted.

Fig 4.12 Retrieved inhibitor coated bar

Fig 4.13 Retrieved simple bar dipped in NaCl solution

4.5RESULTS

4.4.1. Observation of deformed bar embedded in concrete:

Bar dia (mm)	Voltage applied (volts)	Time of first crack (days)	Mass loss (gm)
12	15	6	30.8
16	15	9	17
20	15	9	13.8

4.4.2. Observation of inhibitor coated deformed bar embedded in concrete:

Bar dia (mm)	Voltage applied (volts)	Time of first crack (days)	Mass loss (gm)
12	15	9	10
16	15	12	8.5
20	15	14	6.7

4.4.3. Observation of deformed bars:

Bar dia (mm)	Voltage applied (volts)	Mass loss (gm)
12	15	129
16	15	138
20	15	160

4.4.4. Observation of deformed bars coated with inhibitors:

Bar dia (mm)	Voltage applied (volts)	Mass loss (gm)
12	15	105
16	15	118
20	15	135

CHAPTER 5

CONCLUSIONS

Compiling the results of all the specimens, the following conclusions can be drawn :

- There is no relation between the pattern of crack observed and the voltage applied to the specimens.
- Mass loss of the bars embedded in concrete when coated with inhibitor was found to be less than bars placed without inhibitor coating .
- Mass loss was found to be more when the concrete was porous and large amount of NaCl solution was able to penetrate directly.
- Crack pattern was generally on the upper surface of the specimen perpendicular to the protruded bar.
- Inhibitor coated bars and simple bars were placed directly in NaCl solution to compare with the above results obtained.
- Corrosion was somewhat prevented by the application of inhibitor (Nerolac metal primer).

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