A Thesis on

An Experimental Study on the Effect of Corrosion on Steel Reinforcement of Concrete Member

Submitted for partial fulfillment of award of

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IN

Structural Engineering

By

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DECLARATION

I **Amit Shakya** declare that thesis " **An Experimental Study on the Effect of Corrosion on Steel Reinforcement of Concrete Member**" submitted by mean the partial fulfillment of the requirements for the award of the degree of Master of Technology (Structural Engineering) of Integral University, Lucknow. The thesis is record of my own work carried under the supervision and guidance of **Mr. Muddassir Umer Rizvi (Assistant Professor)**. The thesis has been composed by me and that the work has not been submitted for any other degree or professional qualification. I also declare that in case of any discrepancy I will be solely responsible. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others.

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*Certified that the thesis entitled "***An Experimental Study on the Effect of Corrosion on Steel Reinforcement of Concrete Member***" is being submitted by* ***Mr.*** **Amit Shakya** *(Enrollment No 1900101847) in partial fulfillment of requirement for the* ***Award*** *of* ***Degree*** *of* ***Master of Technology*** *in* ***Structural Engineering*** *of* ***Integral University****, Lucknow, is a record of candidate's own work carried out by her under my supervision and guidance.*

The results presented in this thesis have not been submitted to any other university or institute for the award of any other degree or diploma.

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AMIT SHAKYA
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ABSTRACT

Corrosion is one of the most important factor to achieve in completing the service life of concrete structures also cause significant losses in load carrying capacity of structures. In this study, the reinforced concrete member designed in small geometrical scale was subjected to accelerated corrosion test for 30 days under 1 ampere constant current. As a result of the experiment, weight loss and strength reductions was obtained. Loss of strength in reinforcement due to corrosion damage was obtained with experimental procedure. Loss of cross section and reduction of tensile and flexural strength of concrete members were obtained. As a result of the comparisons, it was observed that corrosion damage caused significant loss in load carrying capacity of the structure.

CHAPTER 1

INTRODUCTION

1.1 General

The deterioration of reinforced concrete structures is a major problem. The primary cause of this deterioration (cracking, delamination and spalling) is the corrosion of steel reinforcing bars due to chlorides. The two main source of chlorides are deicing chemicals and seawater.

1.2 Corrosion

Corrosion is the main deterioration mechanism of metallic materials. Therefore, corrosion prevention by protection of metallic structures is essential for structures safety, integrity, and function and, thus, for long service life. Standardized corrosion protection systems for metallic structures include cathodic protection and a wide variety of coating systems, namely, paint systems and metallic coatings. Since there is no universal solution for corrosion protection of steel structures, the proper system must be selected according to the specified requirements by considering: design, surface preparation, cost, fabrication, performance, and maintenance, as well as expected exposure conditions and environmental aggressiveness. This paper presents, according to relevant international standards, the most common methods for corrosion protection. Special attention is also dedicated to surface preparation, since it is a main influencing factor of the service life of coating systems.

1.3 Types of Corrosion

Corrosion can be classified in a number of ways like low-temperature corrosion and high-temperature corrosion. It can also be categorized as wet corrosion and dry corrosion

Those are

I Pitting corrosion

II Galvanic corrosion

III Cracking corrosion

IV Fatigue Corrosion

1.3.1 Pitting Corrosion

Pitting is the most destructive form of localized corrosion. It results in the formation of small pits or cavities in the substrates It occurs in a very small area of the metal surface while the remaining surface remains unaffected. It is very difficult to predict pitting due to their small size and sometimes pits may be covered with corrosion product. Pitting results in minimal weight loss in the metal substrate, which can lead to a complete failure of the structure.

1.3.2 Galvanic Corrosion

Galvanic corrosion results when two different metal couples in the presence of the electrolyte or corrosive conditions. It is also known as bimetallic corrosion. The essential conditions for galvanic corrosion to occur are two electrochemically different metals should be present, there must be electrical contact between them and both metals should be exposed to the electrolyte. The driving factor for this type of corrosion is the potential developed between the dissimilar metals

1.3.3 Cracking Corrosion

Cracking corrosion is another class of corrosion that leads to sudden failure of the structure. Cracking corrosion generally occurs when ductile metal substrates is subjected to stress at elevated temperature. It includes corrosion fatigue, stress corrosion cracking and hydrogen-damage types of corrosion.

1.3.4 Fatigue Corrosion

Fatigue corrosion arises due to the simultaneous effect of cyclic stress and corrosive environments. The collective effect of these two processes is much more dangerous than alone. It generally occurs at pits, surface defects or irregularities. Fatigue corrosion is similar to stress corrosion cracking in many ways, except it can take place in any environment. In fatigue corrosion, trans-granular propagation is generally observed and does not exhibit branched propagation as observed in the stress corrosion cracking. The extent of fatigue corrosion depends upon factors like environment, loading and metallurgical. Morphology and size of cracks depend on the frequency of stress. High frequency stress results in fine cracks and low frequency stress develops broad cracks.

1.4 Causes of Corrosion in Reinforcement Steel

Corrosion of the steel reinforcement bars may occur due to localized failure of the passive film on the steel by chloride ions or a general failure of the passivity by neutralization of the concrete due to reaction with carbon dioxide from the atmosphere. The main factors responsible for corrosion of reinforcement bars are:

1.4.1 Loss of alkalinity due to carbonation

When the steel surface is left unprotected in the atmosphere, rust begins to form on the steel surface and gradually flakes off.

1.4.2 Loss of alkalinity due to chlorides

Chloride ions tend to de-passivate the steel surface by destroying the alkalinity of the concrete.

1.4.3 Cracks in concrete

Cracks may expose the steel bars to the atmosphere and hence increase carbonation.

1.4.4 Moisture pathways

Regular wetting of the concrete may lead to water reaching the steel reinforcement bars by diffusion through the pore structure of the concrete or cracks present in the concrete. Rusting of the steel bars follow thereafter.

1.4.5 Insufficient Cover

Insufficient dimension of concrete cover.

1.5 Effect of corrosion on steel Reinforcement

Once the steel bars start corroding, the reinforced concrete member gradually begins deteriorating going through the following stages:

1.5.1 Formation of white patches

Atmospheric carbon dioxide reacts with calcium hydroxide present in the cement paste forming calcium carbonate. This calcium carbonate is carried by moisture and deposited onto the concrete surface forming white patches.

1.5.2 Brown patches along reinforcement

When the steel bars start corroding, a layer of iron oxide is formed on it. This iron oxide also gets carried to the surface of the concrete by moisture.

1.5.3 Formation of cracks

The products of corrosion occupy a greater volume than the original material. Hence they exert pressure on the concrete and crack it. With more corrosion occurring, more and wider cracks are formed.

1.5.4 Spalling of concrete cover

Due to loss of the bond between concrete and steel, the concrete starts forming multiple layers of scales and peels off. The steel bars also get reduced in size.

1.5.5 Snapping of bars

Due to reduction in the size of the steel bars, they finally snap. Also, there is a considerable reduction in the size of the main bars.

1.5.6 Buckling of bars

Spalling of the concrete cover and snapping of bars lead to buckling of the main bars. This bulges the concrete in that region and eventually the whole structure collapses.

1.6 How to avoid corrosion of steel reinforcement

Corrosion of steel reinforcement bars may be prevented or at least delayed by practising good measures. Also, damaged steel bars can be repaired and the concrete structure can be restored properly. Some steps are given below:

1.6.1 Providing Sufficient Concrete Cover

A good amount of concrete cover should be provided over the steel reinforcement bars. This ensures proper maintenance of the alkaline nature within the concrete and the passivity of the steel bars. The steel bars should be precisely placed in position

1.6.2 Use of Good Quality Concrete

High quality concrete must be used. It helps to maintain proper alkaline nature. For the concrete, a water/cement ratio of 0.4 or less is to be maintained. Excessive water may damage the steel bars

1.6.3 Proper Compaction fo Concrete

Concrete must be completely compacted such that there are no air voids or pockets present inside

1.6.4 Use of FBE coated Bars

Fusion Bonded Epoxy Coating (FBEC) may be applied on the steel bars to prevent them from corrosion. Epoxy powder is spread electrostatically on to the steel bars. The powder melts and flows over the bars upon heating, forming a protective coating. They are thermoset polymer coatings because application of heat will not melt the coating. Apart from rebar it also has wide application in pipeline construction

1.6.5 Use of Cement Based Polymers

Cement based polymers can be used in the concrete to enhance its protection against corrosion capabilities. The cement based polymers act as a binder in the concrete. They also increase the durability, tensile strength and vibration damping of the concrete

1.7 Corrosion Mechanism

The corrosion mechanism cannot be separated from the electrochemical reaction. Electrochemical reactions involve the displacement of electrons. Electron displacement is the result of a redox reaction (oxidation-reduction). The mechanism of corrosion through electrochemical reactions involves an anodic reaction. Anodic reactions (oxidation) are indicated by increased valence or electron product. The anodic reaction occurring in the metal corrosion process is:

Figure 2. 9 Corrosion Erosion on Seawater Pipe (Bloging, n.d.) Figure 2. 10 Stress Corrosion (Hussaini, n.d.) 16

$$M \rightarrow Mn+ + ne$$

In corrosion of metal M is the process of oxidation of the metal into one ion (n+) in the electron n release. The price of n depends on the nature of the metal as an example of iron:

$$Fe \rightarrow Fe2+ + 2e$$

The cathodic reaction also takes place in the corrosion process. The cathodic reaction indicated by decreasing the valence value or consumption of electrons resulting from the anodic reaction. The cathodic reaction in which oxygen from the air dissolves in an open solution. The corrosion mechanism that occurs in iron (Fe) is written as follows:

$$Fe(s) + H2O(l) + \frac{1}{2} O2(g) \rightarrow Fe(OH)2(s)$$

Fero hydroxide [Fe (OH) 2] is a temporary result which can be oxidized naturally by water and air to ferric hydroxide [Fe (OH) 3], so that the next reaction mechanism is:

$$4\ Fe(OH)2(s) + O2(g) + 2H2O(l) \rightarrow 4Fe(OH)3(s)$$

The hydroxide ferries that are formed will turn into a brownish-browned Fe2O3 which we usually call rust. According to Vogel (1979) Reactions are: $2Fe(OH)3 \rightarrow Fe2O3+ 3H2O$ In general, the corrosion mechanism occurring in a solution starts from the oxidized metal in the solution and releases the electrons to form positively charged metal ions. The solution will act as a cathode with a common reaction is the release of H2 and reduction of O2, due to reduced H + and H2O ions. This reaction occurs on the surface of the metal which will cause exfoliation due to dissolving the metal into the solution repeatedly.

CHAPTER-2
LITERATURE REVIEW

J Revathy, K Saguna, PN Raghunath (2009) - In this paper,an experimental investigation was carried out on reinforced concrete columns with corroding reinforcement to assess the residual strength and ductility performance of columns.

O.O. Akinyemi, and O.J. Alamu (2009) - From the experiment results,

1. That the coating (i.e. bitumen, enamel paint, and local anti-rust paint) offered good protection against corrosion within the period of experimental investigations. However, this protection could not be guaranteed at longer period.
2. That the enamel paint coating has the best protection against corrosion, followed by bitumen coating, and lastly local anti-rust paint coating in the corrosive media used (i.e. sodium chloride solution).
3. That the concrete cover to reinforcing steels also offered good corrosion protection with the 50mm thickness having the best protection followed by 25mm thickness, and finally 10mm thickness.

O.S.I Fayomi and A.P.I Popoola (2012) - Proper electrodeposition of mild steel using zinc particle was carried out. The microhardness and corrosion behaviour of the resultant deposition were investigated with the following deductions:

1. The average increase in microhardness of the mild steel substrate was 55 HVN to deposited sample Zn 3 was 108 HVN, about twice the microhardness value of the mild steel was achieved.

2. The corrosion resistance of mild steel was improved after zinc deposition. The sample produced with the highest applied voltage displayed the best microhardness value, and had the highest corrosion resistance. This was featured by a decrease in corrosion current density and corrosion current, increase corrosion potential and the polarization resistance.

3. The pitting corrosion attack suffered by Zn 1 is attributed to fewer ionic migrations, meaning that only few hydrated ion(s) in the electrolyte migrated toward the cathode under the influence of the applied voltage.

4. The order of corrosion resistance is sample 3>2>1.

Aleksandra Bochenek (2012) - Presenting different cases of concrete corrosion it was shown that its durability is assured when three principles are observed:
1. Low permeability – low w/c ratio and high content of C-S-H gel which tighten pores; thus cements rich in pozzolana addition is promoted.
2. Suitable cement phase composition containing low C_3A content in Portland cement clinker.
3. Low alkalis content, principally potassium, because cement produced in Europe has, as a rule, low sodium content.

Api Popoola, OE Olorunniwo and OO Ige (2014) - Selective modification methods such as dipping, spraying, sol-gel, vapour deposition among others of metals and components is possible through the application of anticorrosion coatings, therefore only the part which is at risk to degradation needs to be coated, leading to cost reduction as opposed to other traditional prevention methods. Material loss and component failures can be prevented with proper selection of coatings/ materials in most manufacturing industries. Adequate knowledge of these processes is therefore inevitable

Jin Xia, Ph.D.1; Wei-Liang Jin, Ph.D.2; and Long-Yuan Li (2015) - This paper presents an experimental investigation on the performance of RC columns with corroded reinforcing steel bars

Deepak Dwivedi,a Kateˇrina Lepkova´ and Thomas Beckerb (2016) - This article addresses the importance of material properties, such as surface texture, energy, morphology and defects in carbon steels used under corrosive conditions, and provides a critical review of the current state of surface analytical methods available for the carbon steel surfaces.
As carbon steel continues to be the preferred construction material across industry yields, understanding the corrosion mechanisms and the function of corrosion inhibitors, involving the reactions at the interfaces between the corrosive electrolyte and a steel surface, particularly at the initial stages of the corrosion process are required.

Anil Kumar (2016) - The present investigation tried to explore types of inhibitors, nature of inhibitors, their mechanism and also to explore whether the simple polarization technique can be used to compare the efficiency of most prevalent inhibitors. The findings indicate that performance wise (a) nitrate salts are more efficient than nitrite salts (sodium and calcium); (b) calcium salts are more effective; (c) further, it was observed that molar concentration wise calcium salts offer greater efficiency; and (d) molybdates and tungstates are almost comparable in their inhibitive efficiency in terms of Icorr values, however, tungstates show comparably better inhibitive efficiency in protecting steel reinforcement corrosion in concrete.

Pusuluri Sri harsha, Sumith Kumar, Birudala Raga Harshith Reddy, Rontala Saketh Reddy (2017) - In this paper, a detailed study of ceramic coatings, the mechanism of corrosion and different forms corrosion is also studied to explain the importance to ceramic coatings in providing the corrosion resistance to the materials. Many works are studied and summarised their results.

Aizada Kalmagambetova Tatyana Bogoyavlenskaya (2019) - A comparative analysis of the nature of the demolition of the specimens showed that there is demolition along the edge “Waterproof outer casing of polyethylene- Polyurethene Thermal insulation.

Majid H. Abdulmajeed, Hiba A. Abdullah, Slafa I. Ibrahim, Ghaith Z. Alsandooq (2019) - Producing eco-friendly coating was done by applying polypyrrole coating doped by coumarin on carbon steel. Some techniques were confirmed the obtaining compact and adhesive film. Addition of coumarin to coating gave more roughness and average diameter due to the difference in size of molecules and polymer chains.

2.1 INFERENCES FOR LITERATURE REVIEW

On the basis of the above literature review, the following inferences are found

- The ultimate strength was reduced by 3% for 10% of corrosion-damaged column.
- The column with 25% degree of corrosion damage showed a reduction in load capacity by 12%.
- After 26.5 days, 663.61 gr of theoretical weight loss was expected in the reinforcements.
- The yield strength of the longitudinal reinforcement was 441 MPa and the yield strength value was obtained as 386.2 MPa after the corrosion process.
- The corrosion products resulting from the corrosion of steel reinforcing bars occupy a volume equal to three to six times that of the original steel.

2.2 Research gap

For comparison of the strength, experimental study is to be done by comparing the yield strength of steel reinforcement bar before and after corrosion in the samples. And also compare the flexural strength of beams before and after corrosion.

2.3 Objectives

1. To determine flexural strength of reinforced concrete beams.

2. To compare the weight of reinforcements before and after corrosion.

3. To study yield strength of reinforcement bar.

CHAPTER-3
METHODOLOGY

3.1 General

The method of research conducted in this case is the experimental method of 6 column and 6 beams. For accelerating the corrosion in the specimens NaCl content is used. Amount of NaCl content is 0.5% is used.

3.2 Materials

For Columns

The specimens of column were 150 mm in diameter and 600 mm in height. The specimens were cast with a M25 grade of concrete. The specimens were provided with four bars of 10 mm diameter as longitudinal reinforcement. Each specimen also contained 8 mm diameter stirrups with a spacing of 115 mm c/c. The specimens were cast in an mould of internal diameter 150 mm. The longitudinal bars were kept protruded from the column face to accommodate the electrical connections for accelerated corrosion.

For Beams

The specimens of Beam were 150 mm *150 mm in cross-section and 700 mm in length. The specimens were cast with a M25 grade of concrete. The specimens were provided with four bars of 10 mm diameter as longitudinal reinforcement. Each specimen also contained 8 mm diameter stirrups with a spacing of 115 mm c/c. The longitudinal bars were kept protruded from the column face to accommodate the electrical connections for accelerated corrosion.

Steel

Characteristic strength of reinforcement steel is (HYSD BARS) fy =500 N/mm^2

NaCl Content

NaCl with amount 0.5 % used for salinity in water for faster corrosion

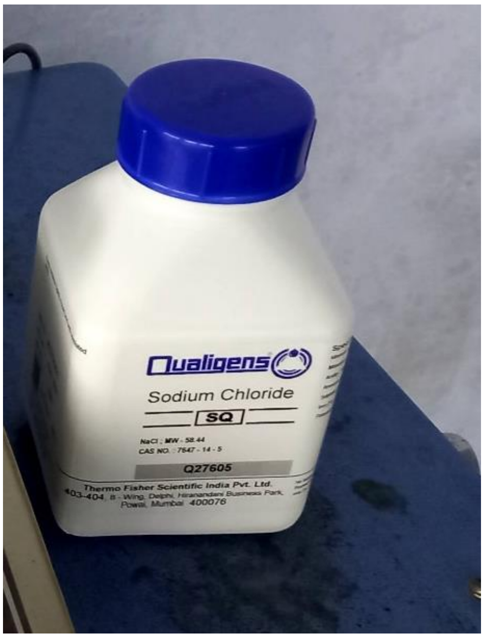


Figure : NaCl Content

3.3 Accelerated Corrosion Technique

Accelerated Corrosion Technique: In this study the accelerated corrosion method is used to induce accelerated corrosion in bars in concrete. To induce current in bars DC power supply of 1 ampere is used. 0.5% concentrated NaCl is used as electrolyte solution. Specimens are placed in NaCl solution for a month to induced corrosion.

Devices are used :

1. Ammeter
2. Auto-Transformer
3. Rectifier

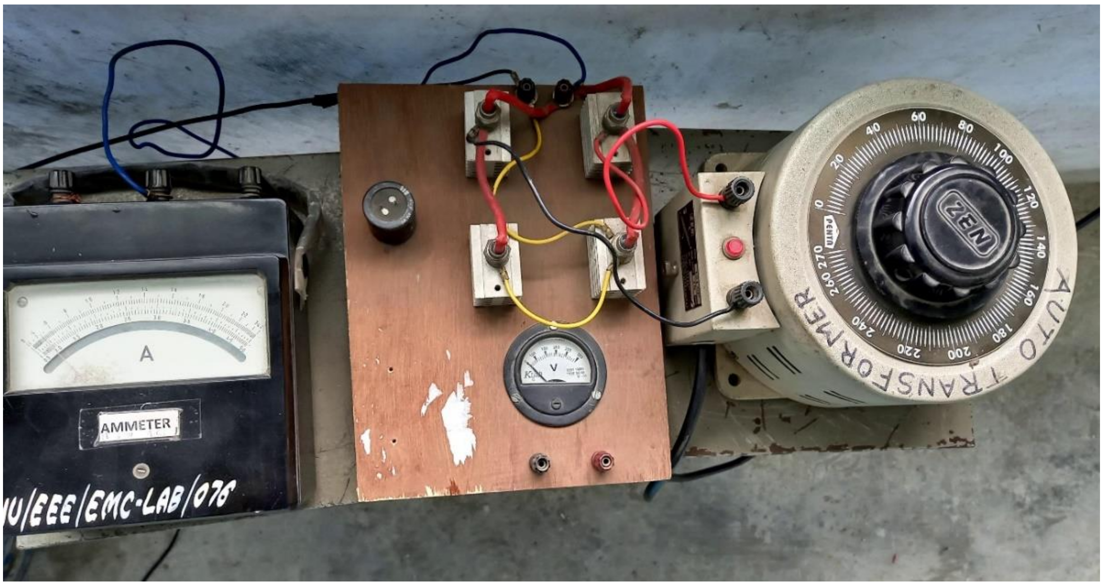
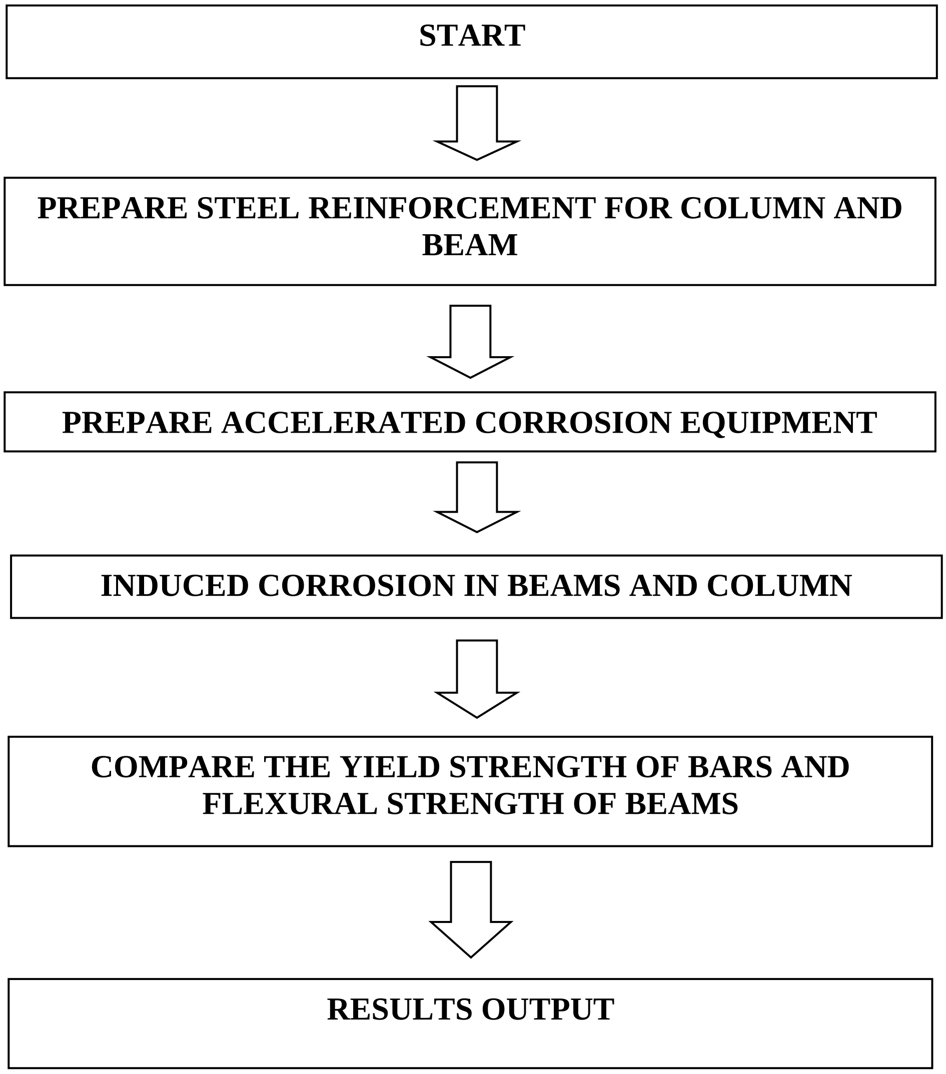


Figure : Accelerated corrosion devices

Figure : View of Accelerated Corrosion Equipment

3.5 METHODOLOGY FLOW CHART



CHAPTER 4
RESULTS AND DISCUSSION

This chapter deals with the results obtained from the testing of the samples

5.1 Two Point Loading Test

Results of Two-point Loading test are tabulated in table given below:

Conditions	Beam Specimens	Ultimate Load (N/mm^2)	Average (N/mm^2)
Non- Corroded	1	1.18	1.41
	2	1.57	
	3	1.48	
Corroded	1	1.1	1.26
	2	1.37	
	3	1.33	

Figure : Beams before corrosion

Figure : Beams after corrosion

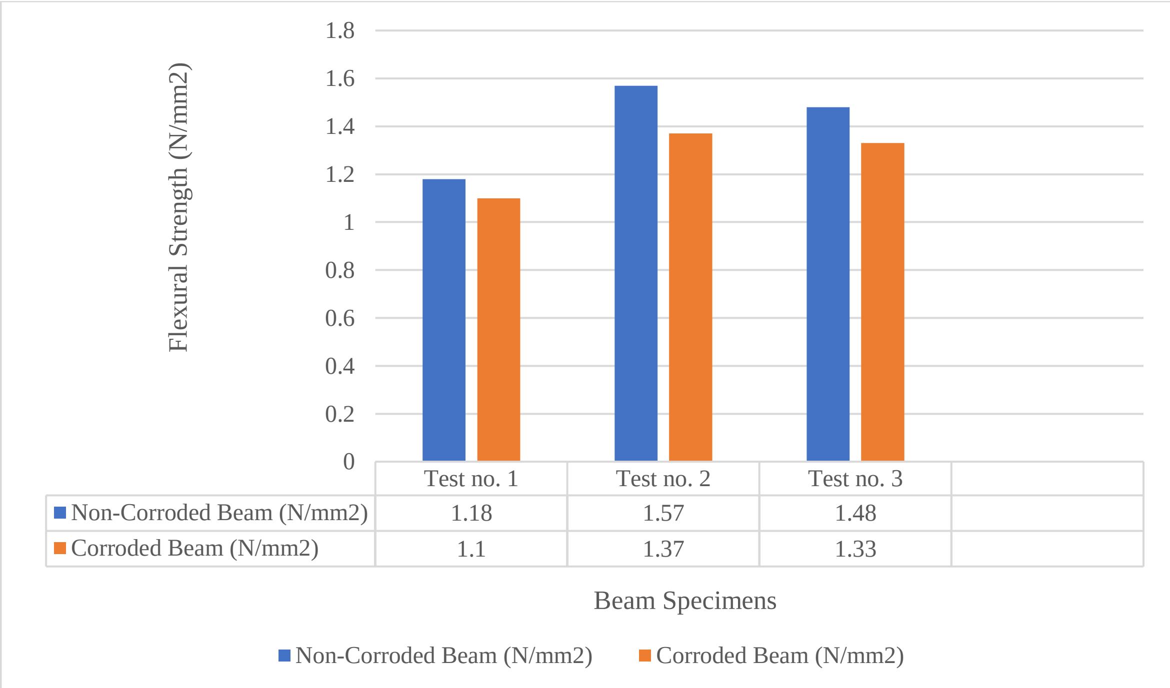


Figure 9 : Chart representation of Flexural Strength of Beams

5.2 Tensile Strength

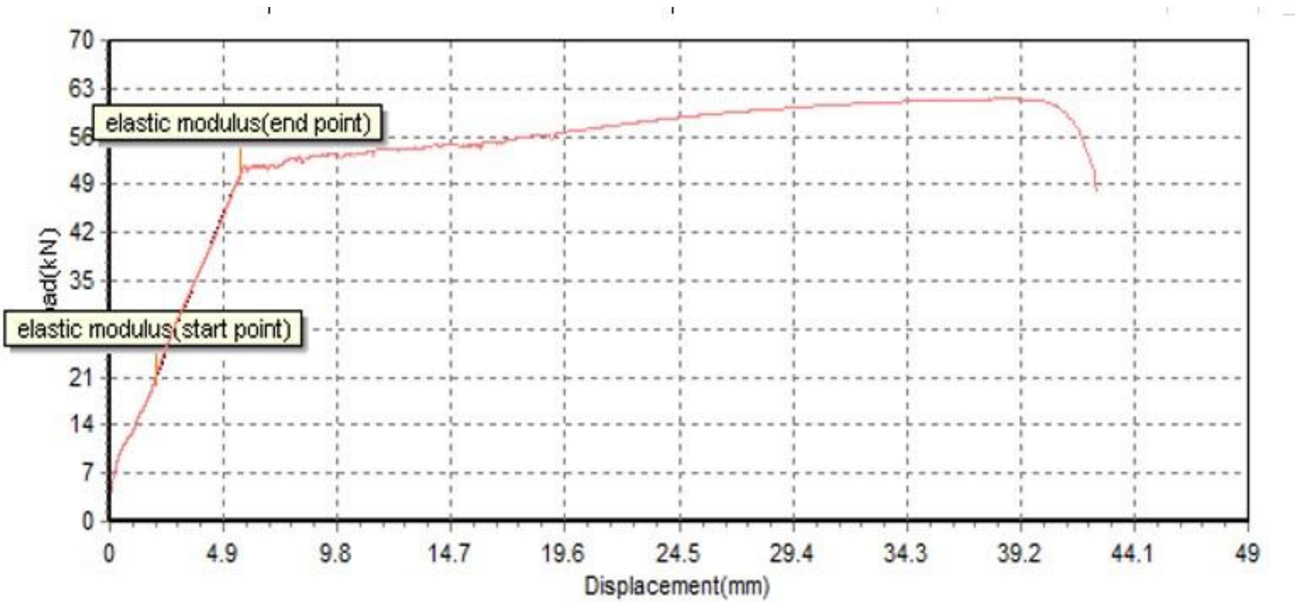
Conditions	S no.	Bar Dia	Tensile Strength (Mpa)	Average (Mpa)
Non-Corroded	1	10 mm	839.5	792.6
	2	10 mm	778.9	
	3	10 mm	759.4	
Corroded	1	10 mm	580.4	685.36
	2	10 mm	736.8	
	3	10 mm	738.9	

Figure : view of Corroded-bar at the time of tensile strength testing

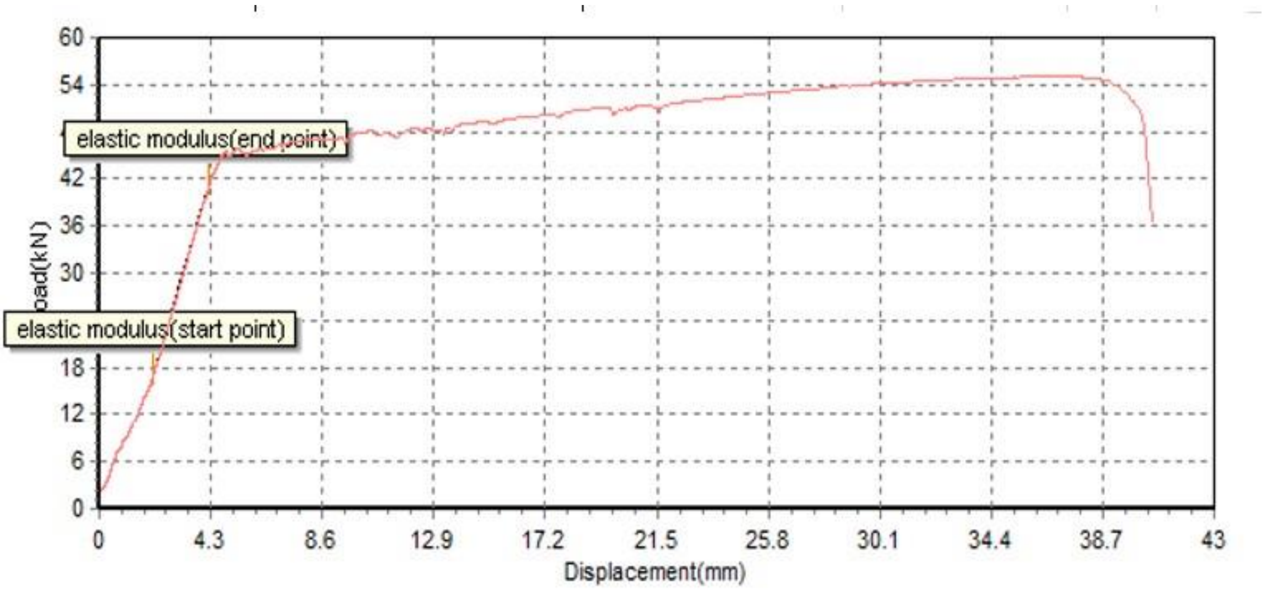
5.2.1 Graphical representation of tensile strength of bars

(a) Corroded Bars

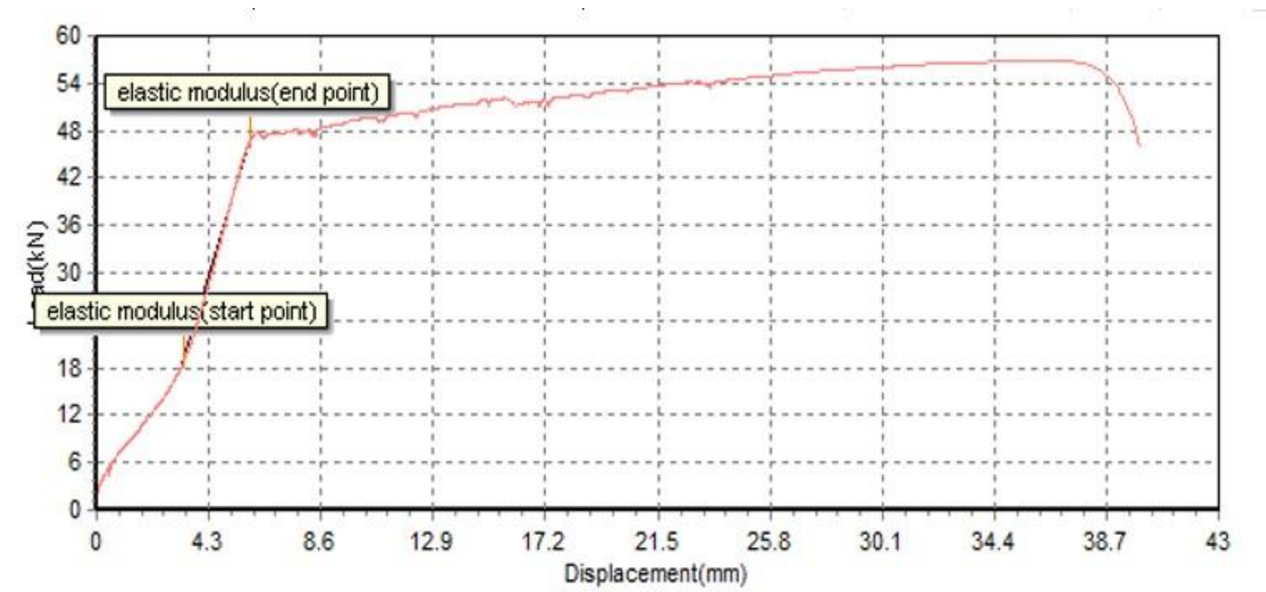
Bar 1



Bar 2

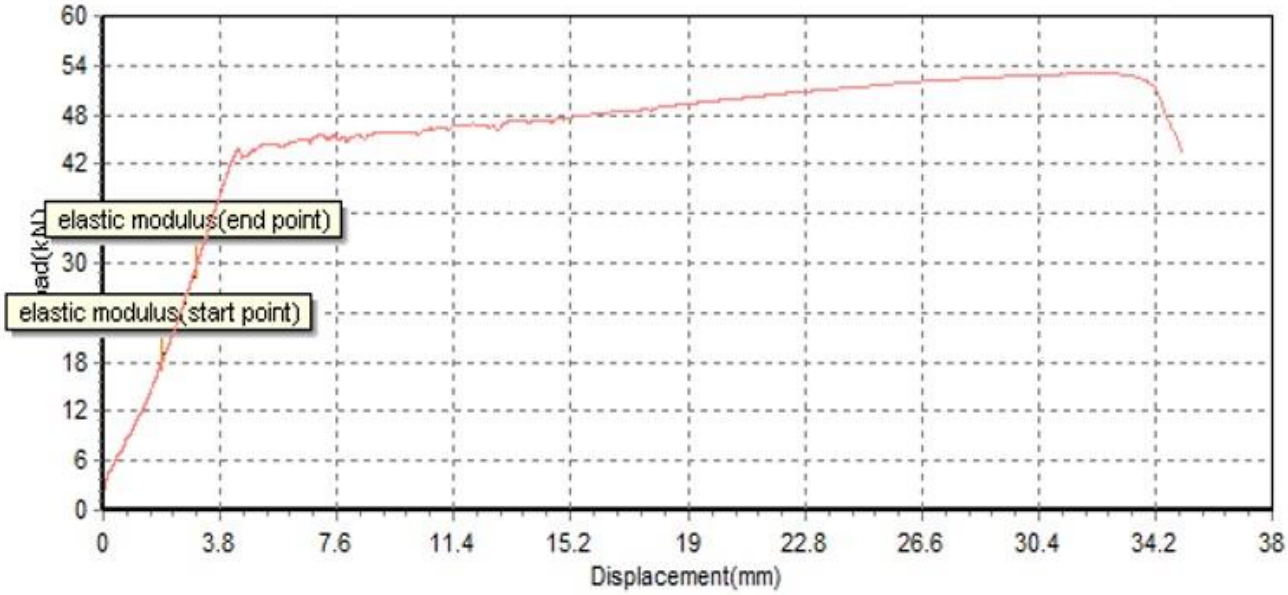

60
54
42
36
30
18
12
6
0
elastic modulus(end point)
elastic modulus(start point)
oad(kN)
0
4.3
8.6
12.9
17.2
21.5
25.8
30.1
34.4
38.7
43
Displacement(mm)

Bar 3

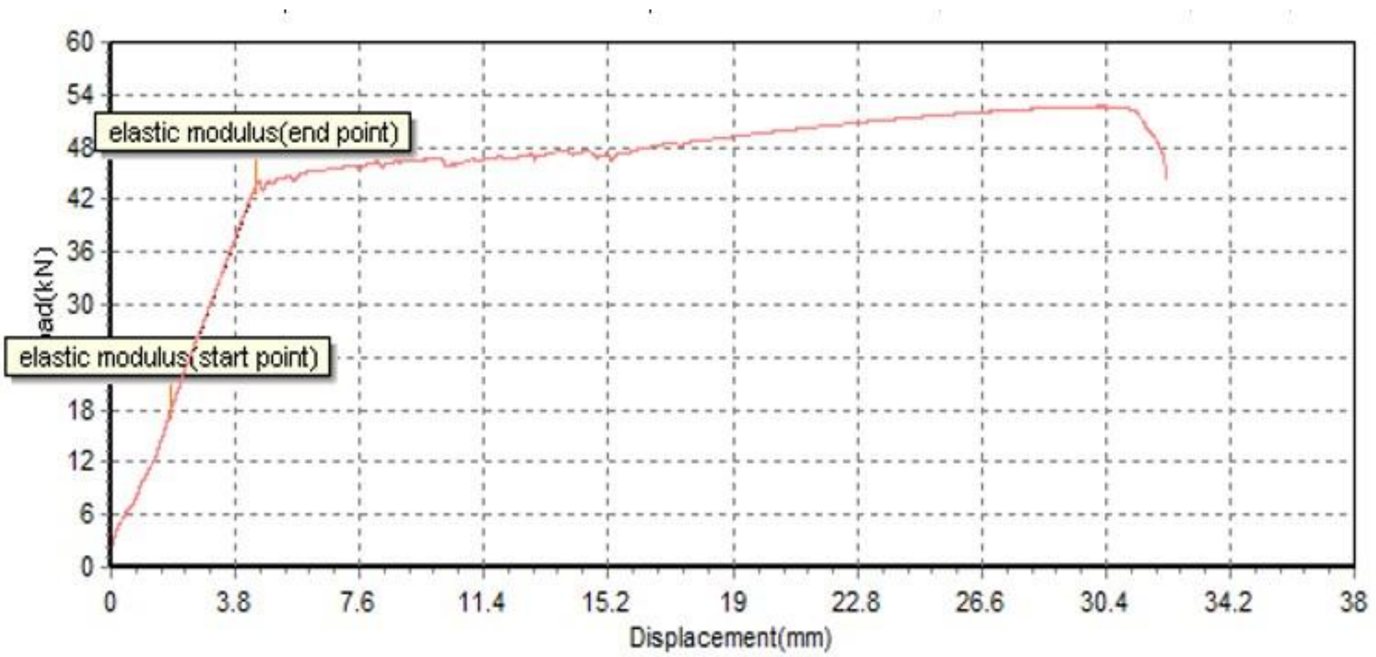

60
54
48
42
36
30
18
12
6
0
elastic modulus(end point)
elastic modulus(start point)
ad(kN)
0
4.3
8.6
12.9
17.2
21.5
25.8
30.1
34.4
38.7
43
Displacement(mm)

(b) Corroded Bar

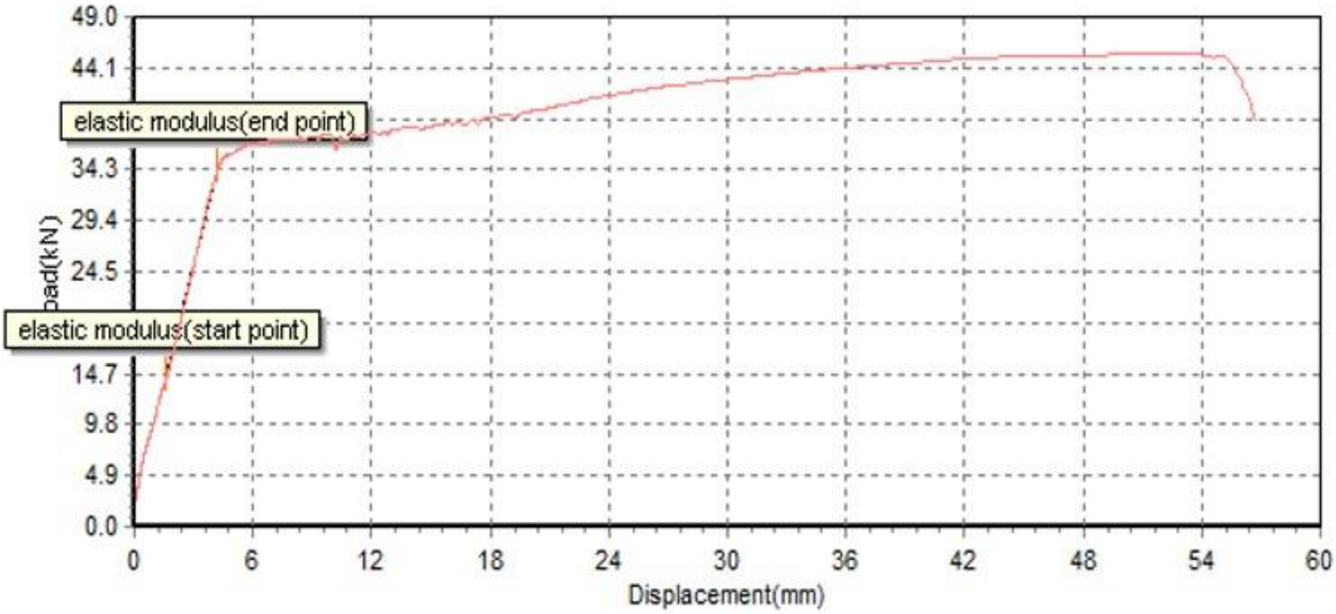
Bar 1



Bar 2



Bar 3



5.3 Weight test

After a month, a weight loss of 4% was obtained in specimens. Weight of specimens before corrosion was 2127.5 gm. But after accelerated corrosion in specimens, weight of specimens found 2050 gm.

CHAPTER 5
CONCLUSION

Based on the results presented, the following conclusions are drawn:

1. Corrosion of the main steel bar causes surface concrete cracking.

2. Corrosion usually results in a weakened bond which usually takes place at the interface of concrete and corroded bars.

3. Due to weight loss of the reinforcement bars, causes significant losses in the load carrying capacity of the whole structure.

4. Reduction of flexural strength in beams leads to deflection in structure.

5. Stirrups bars reduces their diameter much more faster than longitudinal bars.

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