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# EFFECT OF CORROSION ON PERFORMANCE OF RCC BEAMS

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## ABSTRACT

One of the major problems encountered in design life of any structure is deterioration due to corrosion. Many studies have been done to determine effect of corrosion on reinforced concrete members. The studies basically focused on the performance of members with either all bars corroded or bar corroded. The study evaluates the experimental effect of corrosion on the performance of reinforced cement concrete beams. The steel bars used as main reinforcement in the beams were artificially corroded using accelerated corrosion technique. The corroded main reinforcement was laid in all possible combinations. Flexure test was done on 14 standard beam specimens casted with different combinations of corroded and non-corroded bars after 28 days of curing. From the results of tests, it was observed that not only the corroded reinforcement reduces the flexure strength of beams, but also the position of corroded main reinforcement bars affect the strength of beam considerably. Beams with corroded bars near edges of beam showed less strength than the beams with corroded bars near central portion. 3 cylinders were casted for testing bond strength between concrete and corroded, non-corroded and reinforcement bars coated with synthetic resin for corrosion prevention. Tests implied that corrosion of bars done for experiment was not enough to affect the bond strength while synthetic resin reduced the bond strength. The results obtained stand useful for retrofitting works and optimum way of strengthening damaged beams can be worked out.

***Key Words**: Accelerated corrosion, Flexural strength, Anti-corrosive treatment.*

## I. INTRODUCTION

A French gardener, Joseph Monier first invented the reinforced concrete in the year 1849. Reinforced concrete can be used to produce frames, columns, foundation, beams etc. Reinforcement material used should have excellent bonding characteristic, high tensile strength and good thermal compatibility. Reinforcement requires that there shall be smooth transmission of load from the concrete to the interface between concrete and reinforcement material and then on to reinforcement material. Thus the concrete and the material reinforced shall have the same strain. When the Reinforced Concrete Construction began to be widely used, replacing almost completely the hitherto used construction materials viz. Timber, (stone) Masonry and steel sections etc. The life expectation of the R. C. structures was of the order of 100 years. However, at the turn of century we find these expectations belied and ironically newer constructions say 20 to 25 years old, show serious deterioration and distress.

The durability of concrete has become a highly discussed topic in global development. Even though several factors are responsible for early distress in reinforced concrete structures it was observed that in majority of cases, it was because of the corrosion of steel.

The corrosion seems to be an all-pervasive phenomenon causing widespread destruction of all types of structures in all countries across the world and has come to be termed as ‘Cancer’ for concrete.

Corrosion is caused by the destructive attack of chloride ions penetrating by diffusion or other penetration mechanisms from the outside, by incorporation into the OPC concrete mixture, by carbonation of the cement cover, or their combination. Carbonation of concrete or penetrations of acidic gases into the concrete causes reinforcement corrosion. Fig. 1 shows progression of carbonation.

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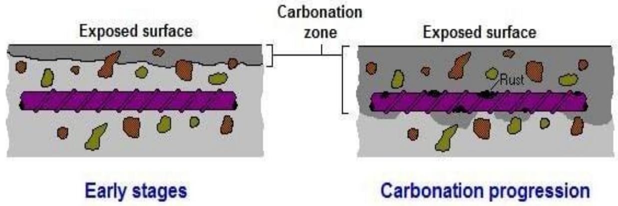


***Figure 1: Progression of carbonation***

Besides these there are few factors, some related to the concrete quality, such as w/c ratio, cement content, impurities in the concrete ingredients, presence of surface cracking, etc. and others related to the external environment, such as moisture, bacterial attack, stray currents, etc., which affect reinforcement corrosion. Uncontaminated cover concrete provides a physical barrier that prevents the direct exposure of the steel surface to the outside environment. It also provides a highly alkaline chemical environment that protects steel from corrosion.
Chloride ions from the external environment diffuse through concrete to the steel surface, leading to the de-passivation of the protective layer and ultimately to the initiation of reinforcement corrosion. Corrosion consumes iron of the reinforcing bar progressively thereby reducing the cross sectional area. Corrosion increases its volume 2 to 6 times than that of the original steel; it causes volume expansion developing tensile stresses in concrete.

The corrosion of rebar in concrete is generally considered as an electrochemical process. With attention of researchers focusing towards the prediction of the residual life of reinforced concrete structures affected by reinforcement corrosion, the use of electrochemical techniques for the determination of relevant parameters in this regard becomes a major area of study. Therefore the electrochemical techniques are widely used for the study of rebar corrosion in laboratories together with their application to real life structures.

## II. LITERATURE REVIEW

Chaitanya and Krishna (2014) analyzed experimentally the strength of corroded beams using Ordinary Portland cement. Accelerated corrosion technique was adopted to corrode the beam experimentally. Beam specimens were prepared using M20 grade concrete for OPC. It was observed that all the corroded beams formed cracks. The cracks perpendicular to the reinforcement were observed on extreme tensile face of beam. It was concluded that the as the rate of corrosion increase above 5%, the ductility property of beam specimen goes on reducing. The relationship between load and end beam deflections for different beams was observed.

Charles (2018) studied the effect of corrosion of reinforcement on bond strength. Bars were corroded with the accelerated corrosion method inside the specimen and pull out tests were conducted with and without confinement reinforcement. The load versus free slip behavior was studied. The experimental study on concrete slab specimens with corroded reinforcement was performed. One steel bar was used as reinforcement to evaluate the effect of corrosion level on bond stress. It was found that the bond stress increased before corrosion level reached 2% and then decreased. The experiments conducted on 150 mm × 150 mm ×150 mm concrete cubes with a single ribbed bar of 12 mm diameter with and without the coating of ficusglumosa resin which was a corrosion inhibitor concluded that the application of resins on reinforcement reduced the corrosion also improved the bond strength between concrete and steel bars. Non-corroded and resin applied test values observed were all higher than the corroded values.

Otunyo (2017) showed that the corroded beams had higher deflection than non-corroded and coated ones as a result of the degradation in the flexural stiffness due to corrosion. Whereas non-corroded and dacryodesedulis coated steel members exhibited higher flexural strength failure loads, had lower mid-span deflection and elongation when compared to the corroded steel members. There was no significance difference between the values for the non-corroded and the dacryodesedulis coated members.

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## III. ACCELERATED CORROSION

Stainless steel, an alloy of iron and chromium are very difficult to rust. Cast iron or wrought iron rust most easily. In order to corrode the bar for experimental work, following method was adopted.

- Hydrochloric acid was measured 150 ml for 10 of water in a glass container.
- A short length of copper wire was wrapped into a coil and submerged it in the acid as shown in Fig. 2 for about a week. This dissolving copper into the acid solution creates a wash that will speed the rusting process.
- Copper was kept to soak by keeping cap loose. The gases produced during the chemical reaction caused pressure to build inside the bottle
- The copper was then removed from the solution using hand gloves and was discarded after some of copper dissolved in the solution. The solution was hence kept undisturbed for 7 days.
- Then the bars were washed with water to clean them from dust and rust was then kept submerged in the solution.
- Bars were then kept for 1 day for corrosion. The corroded bars after one day are shown in Fig. 3.

*Figure 2: Preparation of Solution for Accelerated Corrosion*

*Figure 3: Bars Corroded in Solution*

## IV. CONCRETE MIX DESIGN

The tests required for concrete mix design such as fineness of sand and aggregate, specific gravity of aggregates were conducted and a detailed mix was designed. OPC43 cement was used for mix design of M20. The mix design was according to IS 10262. For determination of targeted strength of concrete three cubes of concrete were casted as per mix proportion. The tests were conducted after 28 days equivalent curing in accelerated curing tank.

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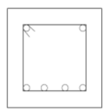
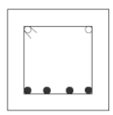
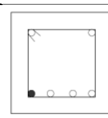
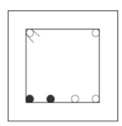
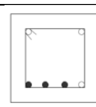
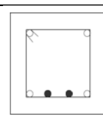
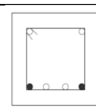
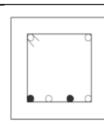
## V. CONFIGURATION OF BARS IN THE BEAM

In reinforced concrete structures, practically all the bars will not be affected by corrosion at the same time or in some cases only few bars out of the reinforcement will be corroded. This variance occurs due to the site condition, exposure of the structural member, deficiency of concrete, cracks or weak spots in the concrete due to improper casting. The bars which are very prone to corrosion will corrode first for example, if a beam is casted at end of the building then one face of the beam is exposed to the atmosphere and the bars near to this face will corrode first than other bars. The corrosion of bars was carried out by accelerated corrosion technique and during casting the bars were laid in all possible combinations of 4 numbers of 10 mm diameter bars in tension zone as depicted in Table 1 and 3 numbers of 10 mm diameter bars in tension zone as depicted in Table 2.This specimens were then tested for flexural load carrying capacity.

**Table 1: Configuration of 4 Numbers 10 mm Diameter Bars**

| Sr. No. | Description | Figure | Remark |
|---|---|---|---|
| 1 | No bars are corroded |  | Results for 0% main reinforcement bars are corroded are obtained |
| 2 | All bars are corroded |  | Results for 100% main reinforcement bars are corroded are obtained |
| 3 | Only 1st bar is corroded |  | Results for 25% main reinforcement bars are corroded are obtained |
| 4 | Only 1st two bars are corroded |  | Results for 50% main reinforcement bars are corroded are obtained |
| 5 | Only 1st three bars are corroded |  | Results for 75% bars are corroded are obtained |
| 6 | Central two bars are corroded |  | Results for 50% bars are corroded (different combination) are obtained |
| 7 | Extreme two bars are corroded |  | Results for 50% bars are corroded (different combination) are obtained |
| 8 | Only 1st and 3rd bars are corroded |  | Results for 50% bars are corroded (different combination) are obtained |

- indicates corroded bar

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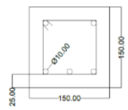
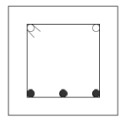
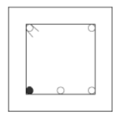
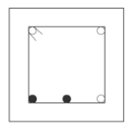
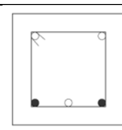
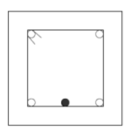
*Table 2: Configuration of 3 Numbers 10 mm Diameter Bars*

| Sr. No. | Description | Figure | Remark |
|---|---|---|---|
| 1 | No bars are corroded |  | Results for 0% main reinforcement bars are corroded are obtained |
| 2 | All bars corroded |  | Results for 100% main reinforcement bars are corroded are obtained |
| 3 | Only 1st bar is corroded |  | Results for 66.67% main reinforcement bars are corroded are obtained |
| 4 | Only 1st two bars are corroded |  | Results for 66.67% main reinforcement bars are corroded are obtained |
| 5 | Extreme two bars are corroded |  | Results for 66.67% main reinforcement bars are corroded (different combination) are obtained |
| 6 | Central one bar corroded |  | Results for 33.33% main reinforcement bars are corroded (different combination) are obtained |

## VI. METHODS

**Flexure Test as per IS 516**

The flexure test specimens of concrete were casted in the laboratory. Total fourteen RCC beams were casted of size 150 x 150 x 700 mm as shown in Fig. 4 and Fig. 5. Six beams were casted in standard sized mould with 4 no. and 3 no. of main reinforcement bars respectively (corroded and non-corroded) with different combinations as shown in Table 1 and Table 2.

The test specimens were stored in a place, free from vibration at a temperature of 27° ± 2°e for 24 hours ± l hour from the time of addition of water to the dry ingredients. After this period, the specimens were marked and removed from the moulds immediately submerged in clean, fresh water and kept there until taken out just prior to test. Tests age of the specimens used for flexural strength test was 28 days. After 28 days curing completed, the beams were taken out and tests were conducted and the flexural test was conducted as per IS 516 on sample immediately on removal from the water whilst they were still in a wet condition. The dimensions of each specimen were noted before testing.

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*Figure 4: Reinforcement Work*

**Figure 5: Casting of Beams**

The specimen was placed in in the testing machine as shown in Fig. 6. The axis of the specimen was carefully aligned with the axis of the loading device and beam was placed without packing between the bearing surfaces of the specimen and the rollers. The load was applied gradually on beams and increased until the specimen failed, and the maximum load applied to the specimen during the test was recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure was noted.


*Figure 6: Set Up for Flexure Test*

**Calculation**

The flexural strength of the specimen expressed as $f_b = \frac{p \times l}{b \times d^2}$

When 'a' is greater than 20.0 cm for 15.0 cm specimen, or greater than 13.3 cm for a 10.0 cm specimen, or

$$f_b = \frac{3p \times a}{b \times d^2}$$

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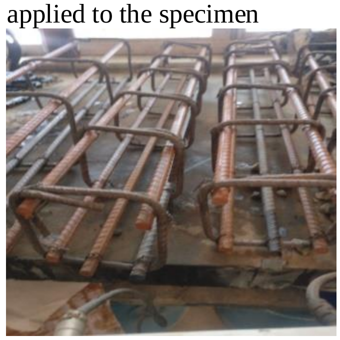
When 'a' is less than 20.0 cm but greater than 17.0 cm for 15.0 cm specimen or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen

where,
b = measured width in cm of the specimen,
d = measured depth in cm of the specimen at the point of failure,
l = length in cm of the span on which the specimen was supported
p = maximum load in kg applied to the specimen



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When 'a' is greater than 20.0 cm for 15.0 cm specimen, or greater than 13.3 cm for a 10.0 cm specimen, or

$$f_b = \frac{3p \times a}{b \times d^2}$$

When 'a' is less than 20.0 cm but greater than 17.0 cm for 15.0 cm specimen or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen

where,

b = measured width in cm of the specimen,
d = measured depth in cm of the specimen at the point of failure,
l = length in cm of the span on which the specimen was supported
p = maximum load in kg applied to the specimen

If 'a' is less than 17.0 cm for a 15.0 cm specimen, or less than 11.0 cm for a 10.0 cm specimen, the results of the test shall be discarded.

Process of Pullout Test

The bond strength is the measure of the effectiveness of the grip between concrete and steel and has no standard quantitative definition. Three concrete cylinders of 100 mm diameter and 200 mm height were casted and a 10 mm diameter steel rod was placed at the center of cylinder while casting as shown in Fig. 7. The specimens were removed from the moulds after 24 hours as shown in Fig. 8 and were put in water. Pull out test was performed after 28 days of curing. The bond failure was recorded in terms of load.

***Figure 7: Casting of Cylinders***

***Figure 8: Specimens for Test***

## VII. RESULT AND CALCULATION

The average compressive strength of cubes was obtained as 21.4 N/mm2 and this value is satisfactory for M20 grade. Fig. 11 and Fig 12 shows crack propagated at distance of 17.2 and 17.1 cm on tension side for beam no. 2 and 10 respectively. The test results of flexure test are given in Table 4.

*Table 4: Observation Table for Flexure Test*

| SN | a (cm) | P(kg) | l (cm) | B (cm) | D (cm) | $f_b$ (kg/cm$^2$) |
|---|---|---|---|---|---|---|
| 1 | 19.2 | 10015.29 | 60 | 15 | 15 | 170.92 |
| 2 | 17.2 | 9413.86 | 60 | 15 | 15 | 143.92 |
| 3 | 18.7 | 9790.01 | 60 | 15 | 15 | 162.73 |
| 4 | 19.0 | 9664.63 | 60 | 15 | 15 | 163.22 |
| 5 | 18.5 | 9537.20 | 60s | 15 | 15 | 156.83 |
| 6 | 19.3 | 9772.68 | 60 | 15 | 15 | 167.65 |
| 7 | 20.5 | 12442.40 | 60 | 15 | 15 | 221.19 |
| 8 | 17.5 | 11773.7 | 60 | 15 | 15 | 183.14 |
| 9 | 17.8 | 12407.74 | 60 | 15 | 15 | 196.31 |
| 10 | 17.1 | 12014.27 | 60 | 15 | 15 | 182.61 |
| 11 | 17.5 | 11865.44 | 60 | 15 | 15 | 184.57 |
| 12 | 17.6 | 12200.82 | 60 | 15 | 15 | 190.87 |
| 13 | 17.6 | 11979.61 | 60 | 15 | 15 | 187.40 |
| 14 | 17.2 | 11935.78 | 60 | 15 | 15 | 182.48 |

*Figure 11: Cracks in Beam no. 2 after Testing*

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*Figure 12: Cracks in Beam no. 10 after Testing*

Testing on the cylinder specimens for pull out test were conducted as shown in Fig. 13 and the specimen after testing is shown in Fig. 14. The test results of pull out test are given in Table 5.

*Figure 13: Pull Out Test Setup*

*Figure 14: Specimen after Testing*

*Table 5: Observation Table for Pull Out Test*

| Sr. no. | Specimen Type | Failure LoadKN | Bond StressMPa |
|---|---|---|---|
| 1 | Non-corroded bar | 35.5 | 5.65 |
| 2 | Corroded bar | 35 | 5.57 |
| 3 | Non-corroded bar coated with synthetic resin | 30.3 | 4.82 |

**Discussion**

The influence of corrosion steel with respect to location and content shows influence in its performance of flexural strength. The results obtained from the flexure test conducted on 14 beams and pullout test conducted on 3 specimens shows;

***Variation w.r.t. Percentage Corroded Steel***

The variation of flexure strength of beams with 3 and 4 no. of reinforcement bars with respect to corrosion percentage is shown in Fig. 15.

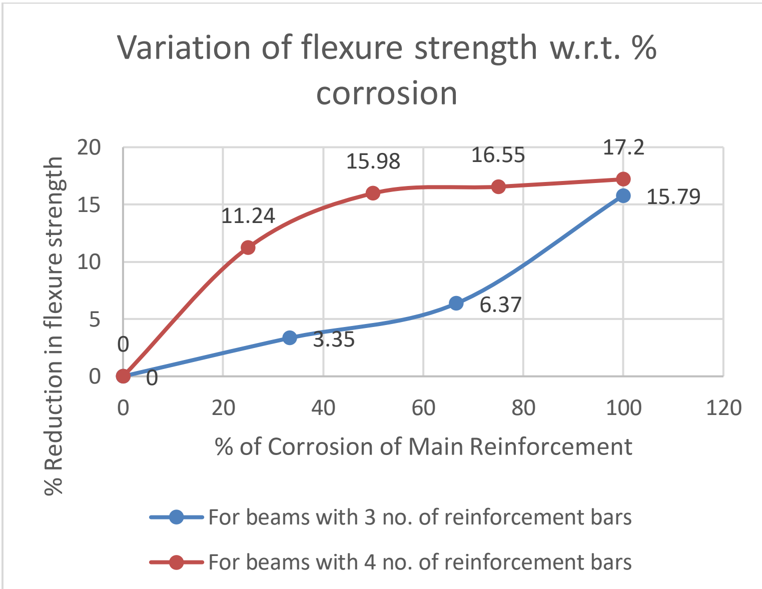


***Figure 15: Graph of Percentage Corrosion vs %Reduction***

As the percentage of corrosion of main reinforcement bars increases the reduction in flexural strength increase. It can also be seen that for beams with 3 reinforcement bars, the rate of decrease in percentage of flexural strength is less than with 4 reinforcement bars. Maximum reduction in flexure strength was observed as 15.79% and 17.2% for beams with 3 and 4 no. of main reinforcement with all bars corroded.

***Variation with change in location of corroded bars***

The location of corroded bar in beam also shows effect on flexural strength of beam.

***Beams with 3 no. of reinforcement bars***

The location of corroded bars also influences the flexural strength of beams. In beams with 3 no. of main reinforcement bars, combinations of corroded bars and variation in flexural strength are shown in Table 6.

***Table 6: Variation of Strength w.r.t. Position of Corroded Bar***

| Sr. no. | Corroded bar | % Reduction in Flexure Strength | Ref Table 2 S No. |
|---|---|---|---|
| 1 | Central bar | 1.91 | 6 |
| 2 | Corner bar | 4.79 | 2 |
| 3 | Both adjacent bar | 4.5 | 4 |
| 4 | Both corner bar | 8.24 | 5 |

When the corroded bars are located near edges of beams, then the reduction in strength is maximum than bars. It was observed that position of corroded bars affect the flexural strength considerably.

**Beams with 4 no. of reinforcement bars**

The variation of flexure strength w.r.t. various combinations of corroded bar in beams with 4 no. of main reinforcement bars, are shown in Table 7.

*Table 7: Variation of Strength w.r.t. Position of 2 Corroded Bars.*

| Sr. no. | Corroded bar | % Reduction in Flexure Strength | Ref Table 1 S No. |
|---|---|---|---|
| 1 | Corner adjucent 2 bar | 17.44 | 4 |
| 2 | Central 2 bars | 13.7 | 6 |
| 3 | Corner bars | 15.27 | 7 |
| 4 | One corner and on inner bar | 17.5 | 8 |

When the corroded bars are near the edges of beams, the reduction in strength is 1.57% more than beams with corroded bars located near center.

**Discussion on Pullout Test Results**

The bond strength of corroded bar is less than that of non-corroded bar. The synthetic resin was coated over the bar and kept in accelerated corrosion solution. The bond strength is considerably reduced as a result of coating the bar with resin. The value is within the permissible limit according to Table 10.1 of IS 456 2000, but as the corrosion level increases the bond strength gets reduced, thus it can be stated that the use of synthetic resin as anticorrosive treatment in RCC beams is unsuitable.

## VIII. CONCLUSIONS

Based on results of the tests conducted following conclusions can be drawn

a. As the percentage of corroded main reinforcement bars increases the flexure strength of the beam specimen reduces.
b. The maximum and minimum reduction of strength for 1.047% of main steel are 15.79% and 3.35% respectively, and for 1.396% of main steel the values are 17.2% and 11.24% respectively.
c. The various combinations of corroded and non-corroded main reinforcement bars with same percentage of corroded main reinforcement steel have shown a reasonable variation. When the corroded main reinforcing bars are near the edges of beam then the reduction in strength was more than the beams with corroded bars located at the central portion.
d. The bars in beams do not corrode simultaneously; depending upon the exposure conditions the bars may undergo asymmetric corrosion. It was observed that beams with asymmetric corrosion bars with respect to vertical axis are less strong than the beams with symmetric corrosion bars of main reinforcement.
e. On applying synthetic resin to avoid corrosion the corrosion levels was reduced but the bond strength also reduced, thus the resin is unsuitable.
f. In retrofitting of beams, the cross section of beam was studied and the location of corrosion and cracks were established, the results obtained can stand useful for retrofitting works and optimum way of strengthening damaged beams can be worked out.

## IX. ACKNOWLEDGEMENT

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