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BOND OF REINFORCEMENT IN CONCRETE WITH DIFFERENT TYPES OF BARS AND PREVENTION OF CORROSION BY USING EPOXY RESIN

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Abstract— **Repair and rehabilitation of existing structures is becoming a major part of the present construction activities. Corrosion of reinforcement is a major contributing factor to the deterioration of reinforced concrete steel structure. Corrosion of reinforcing steel severely influences the bond at the steel-concrete interface. In marine environments and where de-icing salts are applied, the degradation of reinforced concrete structures due to chloride induced corrosion of the reinforcement is a major problem. The expansive nature of the corrosion process results in cracking of the concrete and eventually spalling. The aim of this project is to study the effect of corrosion on bond strength using pullout specimens. The Normal Portland Cement Concrete mixture is used to cast the cubes and in that MS and TMT steel is inserted having diameter 10mm, 12mm and 16 mm. Then that rebar was corroded by passing the current through them. For the corrosion NaCl solution of 5% concentration is used. To prevent the corrosion Epoxy Resin is applied on the rebar. The relationship between the bond strength and weight loss is studied.**

I. INTRODUCTION

Reinforced concrete is one of the most widely used construction materials in the world. It is a versatile and economical material that generally performs its intended use well over its service life. Reinforced concrete is used in numerous ways, some of the larger and better known uses including roadways, bridges, car parks, residential buildings and in industry; for example it is widely used in nuclear power plant. It is in general an excellent construction material. Concrete alone is good in compression, but reinforced concrete greatly increases the scope for making structures required to withstand other forms of mechanical force.

Recently the aspects of concrete durability and performance have become a major subject of discussion especially when the concrete is subjected to a severe environment. Corrosion of steel bars is the main factor influencing both the concrete durability and strength. The corrosion products of the steel reinforcement expand up to seven times the original size, developing high pressures within the concrete, which cause cracking and spalling of the concrete cover and expose the rebar to further corrosion activity. Corrosion reduces the ribs height of the bar which causes reduction in the contact area between the ribs and the concrete leading to reduction in the bond strength.

In marine environments and where de-icing salts are applied, the degradation of reinforced concrete structures due to chloride induced corrosion of the reinforcement is a major problem. The expansive nature of the corrosion process results in cracking of the concrete and eventually spalling. In order to select suitable remedial measures it is necessary to make an assessment of the residual strength and the residual life.

Degradation of reinforced concrete shows up in a variety of ways. Corrosion of rebar produces a bulky reaction product that puts pressure on the surrounding concrete cover which first cracks and eventually spalls. Spalling of the cover gives rise to possible injury, particularly for example in the case of high rise flats or bridges, but extensive corrosion of the rebar itself will lead to mechanical weakening of the reinforced structure. The ultimate result can be collapse of the structure.

A good-quality concrete provides a highly alkaline environment that forms a passive film on reinforcing steel bar surface, preventing the reinforcing steel bar from corroding. However, under a chloride attack or concrete carbonization, this passive film is disrupted and the steel bar begins to corrode. Corrosion of embedded steel bars was a major problem for RC structures for it may affect their residual capacity and life through four aspects, including loss of concrete section as a result of longitudinal cracking and spalling, loss of reinforcement section, change of reinforcement mechanical properties (especially fatigue), and a reduction in bond between reinforcement and concrete. Highway bridges, railroad bridges, and crane girders are continuously subjected to alternate loads that may cause fatigue fracture of reinforcing steel bars. When the RC structure under repeated loads is corroded, its service life can be significantly reduced for the brittle fracture of reinforcing steel bars.

The deterioration of reinforced concrete due to corrosion is a serviceability problem worldwide. The cover zone plays an important role in the durability and serviceability of concrete and provides the initial barrier to aggressive species. Damage to the cover resulting from the accumulation of corrosion products is characterized by cracking, delaminating or spalling of the concrete. The mode of failure is dependent on the cover of concrete as well as rebar diameter. These factors are considered the most influential in cracking initiation of concrete. Hence the study of effect of rebar diameter on corrosion is necessary.

II. LITRATURE REVIEW

Following is the literature for the experiment done by the various researcher references for the present research.

P. C. S. Hayfield

The cathodic protection of steel reinforcing bars in concrete to prevent their corrosion, brought on principally by de-icing salts used on roadways, is at the interesting stage where technology is barely keeping pace with practical demand. It already seems likely that platinum and other noble metals, used in conjunction with titanium and niobium, will play a vital role in several of the protection systems that appear to be the forerunners in a rapidly developing industry.

Vladimír Zivica

Reinforced concrete structures during their exploitation may be exposed to the common action of carbonation and chlorides causing corrosion of steel reinforcement. Therefore, the related data seem to be interesting and important when the evaluation of the service life of the structures is the object of interest. This fact was a motivation for the present experimental study on the sequence of action of chloride solutions and carbonation of the embedding concrete.

Shibin Li, Weiping Zhang, Xianglin Gu and Cimian Zhu

Under badly environmental conditions as well as complex loads, corrosion of embedded reinforcing steel bars in concrete is common for reinforced concrete (RC) structures. Fatigue of corrosion reinforcing steel bars is a key problem for old RC bridges. To assess the residual fatigue life of aged existing RC bridges, the most new study information on fatigue of natural corrosion reinforcement is analyzed, and axial tensile fatigue tests are conducted on fifteen naturally carbonation-induced corrosion steel bars.

The fatigue test results indicate that the existence of corrosion pits reduces the fatigue life of steel bars significantly under the same fatigue stress; with the development of corrosion, the fatigue life of steel bars decays according to negative power exponent law approximately and the attenuation rate increases with stress level augment. For the complexity of fatigue and corrosion, further pertinent conclusions remain to be confirmed.

C. Andrade

Corrosion of reinforcements has extensively being studied during the last 3 decades in spite of which many questions remain unsolved. Steel corrosion embedded in concrete can be suppressed or slown down but at a cost that still has not been correctly accounted from the design phase. The paper reviews some of the subjects, although not all related to the fundamentals of corrosion, the management of the service life and the repair techniques. The task to summarize all important aspects is too wide and much further basic work is needed in the area.

III. PROBLEM STATEMENT

a)Un-proper bonding between reinforcement and concrete.

The effect of corrosion on bond have not be studied extensively. If the steel bars is corroded before it is placed then there is little decrease in bond strength at low corrosion level.

If the corroded bar in concrete in different situation. The expansion of steel and cause cracking of the concrete. This will affect the bond strength. The bars were corroded using impressed current techniques. They found that before appearance of visible cracks, corrosion increase

the bond strength.

b) Corrosion of reinforcement steel bar.

Corrosion is a spontaneous process of returning metals to their natural state by oxidation reduction reactions. Corrosion of metals results in a loss of both structural integrity and attractive appearance. Corrosion of reinforcing steel in concrete is one of the major causes for deterioration

of bridges, buildings and other concrete structures. Corrosion of steel in concrete is attributed to "differential concentration cells caused by non-homogeneity of the concrete and its environment". The main sources of cell potentials are differences in pH, oxygen and chloride content.

IV. OVERVIEW OF UHPC

Corrosion of steel rebar is the major cause of premature failure of reinforced concrete structures. A large number of reinforced concrete structures are subjected to a marine environment, and faced with serious corrosion problem. Epoxy coated rebar becomes a solution and is widely used for corrosion protection of steel rebar in reinforced concrete in marine environment. Various defects to epoxy coating are inevitable during the manufacture, handling, transportation and concrete cast process. The defects of epoxy coating make the steel substrate directly exposed to the aggressive environment, and very much affect the protective properties of epoxy coating on steel rebar in concrete.

Epoxy coatings on rebar are designed to act as a physical barrier, isolating the steel from the three primary elements needed for corrosion to occur—oxygen, moisture, and chloride ions. The coating also serves as an electrical insulator for the steel and minimizes the flow of corrosion current. Though bars completely coated with epoxy won’t rust, their performance depends on the quality and integrity of the coating.

Specimen Preparation

- Cubical Specimens with concentric steel bar will be used.
- Dimensions of specimens used are as per follows:
  - L= 150 mm
  - B= 150 mm
  - H= 150mm
- Before placing the bar in concrete, a groove of 3mm diameter will drilling on one end of the bar for electrical connection.
- Bottom cover is 20mm.
- Different diameter rebars of mild steel and TMT will be used.
  - E.g. 16 mm dia, 12 mm dia and 10 mm dia

- Rebar used are of 1 meter length and they are inserted up to 130 mm into the mould so as to get the bottom cover of 20 mm.
- Concrete is compacted with the help of tamping rod by hand compaction.

Moulding system-

- Moulding system for the preparation of proper specimen consist of holes of different diameter drilled into plywood of table.
- The system was able to accurately maintain the position and inclination of the bar. So, the specimen with concentric bar could obtain.
- Thus the concrete block after 24 hours of casting could be removed entirely from the mould and specimen does not failed during demoulding.

Set up for Corrosion

After the 48 pullout specimens will cast and cured, 12 specimens were subjected to accelerate corrosion by placing them in the accelerated corrosion tanks.

The accelerated corrosion setup consists of 60 cm diameter plastic tank. Electrolytic solution [5% sodium chloride (NaCl) by the weight of water] and a steel mesh placed around the specimen. The specimens will placed in the accelerated corrosion tank and partially immersed with the electrolytic solution up to two third of its height. To eliminate any change in the concentration of the NaCl and pH of the solution. the electrolyte solution will changed on a weekly basis.

The specimen bars will connected to electrical wires by clips then connected to 12 V power supply. Set-ups used for inducing reinforcement corrosion through impressed current consist of a DC power source, a counter electrode, and an electrolyte. The positive terminal of the DC power source is connected to the steel bars (anode) and the negative terminal is connected to the wire mesh (cathode). The current is impressed from counter electrode to the rebars through concrete with the help of the electrolyte (normally sodium chloride solution).

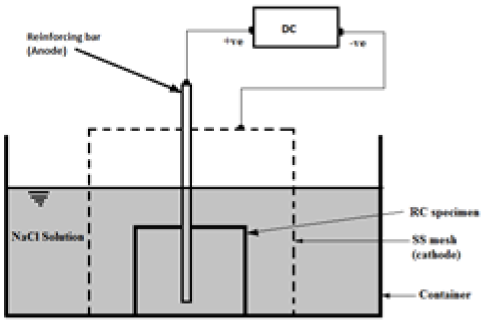

Figure : Schematic Representation of the Device for Accelerated Corrosion

Pull Out Test on Specimen

Object:

To find out the bond strength of mild steel and TMT rebar specimen (both with and without coating)

Test Procedure:

Prepare the specimen by filling the concrete of M20 grade in mould having internal dimensions 150*150*150 mm and insert the mild steel or TMT bar at the centre of specimen. After 28 days curing take out the cubes from water.

Find out pull out load of each specimen with the help of Universal Testing Machine. Find out Bond Stress of each specimen.

Bond Stress is calculated by following formula:

Ʈ= F/ (L*S)

Where

Ʈ= Bond Stress in MPa

F= Applied pulling load in kN

S= Perimeter of rebar

L= Embedded length of rebar= 130 mm

V. APPLICATION

EPOXY COATED BAR India-

Infrastructure projects

(A) Bridge project:-

EPOXY COATED steel bar improve the life cycle cost of concrete bridge decks.

(B) Parking structure project:-

EPOXY COATED steel bar improve the life cycle cost of parking structure project.

Marine structure projects:

- This coated bars do not provide good cathode , thus reduces ring anode .
- The EPOXY coated bars do not corroded.

VI. MIX DESIGN

Mix Design for M20 Grade of Concrete

Assumption

Compressive Strength at 28 days = 20Mpa Maximum size of Aggregate = 12.5mm (angular) Degree of Quality Control = Good.

Type of Exposure = Mild.

Data required

Specific Gravity of Cement = 3.15

Specific Gravity of Fine Aggregate = 2.60

Specific Gravity of Course Aggregate = 2.75

Water absorption Course Aggregate = 0.5%

Water absorption fine Aggregate = 1%

Slump required = 50-100mm.

Free moisture in Sand = 2%

Calculations

Lab Strength= Compressive Strength + (t x S) …….. (Table 1 IS 10262-1982)

=20 + (1.65 x 4)

=26.6 MPa.

To decide w/c ratio which will give 26.6 Mpa strength from IS for Mild exposure w/c ratio should be less than 0.55 so adopt as 0.50

Now from table 4 of IS 10262-1982 Page No 9

For 12.5mm size of aggregate water content per m3of concrete in kg=200kg and Sand as % of total aggregate as40%

To Know Cement Content
W/c = 0.50
c = 200/0.50
=400kg ……………………. (IS 456, Table 5, Page.20)

To decide naturally entrained air from table 3 of IS 10262-1982 for 12mm size as volume of concrete 3%.

Using equation 3.5.1 of IS 10262-1982, Page no. 11

V = $$\left[W + \frac{C}{S_c} + \frac{1}{P} \times \frac{F_a}{S_{fa}} \right] \times \frac{1}{1000}$$

V = $$\left[W + \frac{C}{S_c} + \frac{1}{1-P} \times \frac{C_a}{S_{ca}} \right] \times \frac{1}{1000}$$

Where
V =absorption volume of fresh concrete.
W=mass of water (kg) per m3 of concrete.
C = mass of cement (kg) per m3 of concrete.
Sc = Specific gravity of cement.
P = ratio of fine aggregate to total aggregate by absolute volume.
fa,ca = total mass of fine aggregate and course aggregate in kg/m3.
Sfa,Sca = Specific gravity of saturated surface dry fine aggregate and cours aggregate.
Substituting all the value in formulas, we get
0.97 = [200+400/3.15+1/0.40*fa/2.60] x 1/1000
fa = 669.81 kg/m3
Similarly,
Ca = 1071.70kg/m3
We get

Table No. 3.10: Proportion of concrete

On Basis	w/c	Cement	Fine aggregate	Course aggregate
Mass (kg)	0.50	400	669.81	1071.70
Ratio	0.50	1	1.67	2.67
Bag (per bag)	27 lit	50	83.5	133.5

fig: Pull out Test set up

VII. DISCUSSION

Concrete specimen were casted concentrically with a mild steel and TMT rebar of different diameter such as 16mm,12mm,10mm with and without Epoxy resin coating. Concrete of M20 grade is used. These specimens after demoulding kept for the 28days of curing. The pullout test is carried out on the coated and uncoated specimen after 28days of curing and the bond stress is determined from the pulling force. Some specimens (both Epoxy coated and uncoated)are kept for the accelerated corrosion process atfter the 21 days of curing for the 7 days and observation are taken.

Under the accelerated corrosion test, the epoxy-coated bars show the lowest current readings during the whole period of the immersion time compared to the regular carbon steel bars.

In case of uncoated bar subjected to accelerated corrosion following observations are taken:

- The voltage as well as current between rebars and SS mesh was increased initially and then decreased after cracking of concrete.
- The first crack was observed on 2nd day along with brown stain near steel-concrete interface and corrosion product oozed out from steel-concrete interface.
- The corrosion had started from embedded part of the reinforcing steel.
- Initially green rust was observed for a couple of minutes, then turned to ordinary red rust.
- The more mass loss was found near steel-concrete interface after breaking of specimens.
- The specimen was broken after drying and steel bar was taken out with the help of Pull-out test.
- Then the steel bar was cleaned and scrubbed with a stiff metal brush to make it free from any adhering corrosion products.
- The reinforcing bar was then weighed and percentage mass loss was computed.

- While in case of Epoxy coated rebar subjected to accelerated corrosion, no corrosion of rebar was found.

Thus, complete corrosion protection is achieved by using Epoxy coated rebar.

Table 1 show the effect of temperature variation and different type of curing on geopolymer concrete. In oven heat curing the the temperature varies from 60 ^{0} C to 150 ^{0} C the optimum result we get at 90 ^{0}C with consideration of energy for heating.

In Accelerated curing the effect of temperature on geopolymer concrete will show the optimum result at 80 ^{0}C. Also in membrane curing the effect of temperature varies from 60 ^{0} C to 150 ^{0} C the optimum result we get at 90 ^{0}C. In case of Steam curing the temperature optimize at 100^{0}C.

The fig 1 Shows the Failure pattern of cube on compression testing machine.

VIII. CONCLUSION

- It was found that Failure of all TMT bar specimen was by splitting of the concrete prism.
- While, all the plain (mild steel) specimen failed by slippage of the bar without splitting the concrete mass.
- With the increase in the corrosion level there is a decrease in the bond strength. The decrease in bond Strength will depend on the grade of steel and on the type of steel used.
- Corrosion of reinforcement in concrete decreases with increase in rebar diameter.
- Corrosion of Mild steel reinforcement is more (about 1.5 times) than TMT rebar.
- Bond stress of Mild steel bar is in the range of approximately 52% to 54% of TMT rebar.
- Under the accelerated corrosion test, the epoxy-coated bars show the lowest current readings during the whole period of the immersion time compared to the regular carbon steel bars.
- The low Current reading of the epoxy-coated bars compared to the other used bars implies to the superior effect of the coated bars in corrosion resistance.
- While the sudden increase of the epoxy-coated bars current shows the seriousness of the concrete cracking due to the corrosion concentration in uncoated small area.
- Epoxy coating provided excellent corrosion protection to the steel as long as the coating was not damaged and no corrosion of rebar in concrete takes place.

IX. FUTURE SCOPE

Corrosion of steel rebar is the major cause of premature failure of reinforced concrete structures. Epoxy resin is certainly one of the best industrial adhesive currently on the market. Epoxy resins are thermosetting polymers and known for their high quality performance in various industrial applications for corrosion protection, thermal stability, mechanical strength, moisture resistivity, adhesion,etc

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