Analysing and Evaluating Strength of Rebars by using Epoxy Coated Resin

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Abstract -Bond strength in concrete plays a very crucial role in structural stability and durability. The bond strength between the concrete and the steel reinforcement gets weaker as the concrete ages. The environmental conditions also make the situation tough and therefore steel reinforcement corrodes and thus puts the durability and stability at risk. This study helps in improving the bond strength for the same. The study is made by using different diameters of steel reinforcements either coated with or without epoxy resins and tested for pull out test to know the failure load. The findings in the evaluation is done by creating an alkaline and wet environment just like marine environment. It was seen that the reinforcement with epoxy resin coating performs well even under alkaline, wet conditions and proves to improve the bond strength which ultimately helps in long term durability, structural safety and management.

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Key Words:Steel Reinforcement, Bond Strength, Corrosion, Rebar, Durability, Epoxy Coated Resin (ECR)

1.INTRODUCTION *(Size 11, Times New roman)*

Reinforced cement concrete acronym as RCC is considered as one of the important and widely used construction materials in entire world. Reinforced concrete is a versatile as well as an economical material and performs for what is was designed well over its service life. Reinforced concrete has found its place in numerous construction activities. It is used right from the construction of small residential building to commercial projects like industries, power plants etc. Concrete is also used in infrastructural projects like roads, bridges, dams, ports etc. It is in general an excellent construction material. Concrete in absence of embedded reinforcement will always be good in compression, but when reinforced concrete is taken into consideration it greatly increases the scope for making structures to withstand even other forms of mechanical force.

Concrete durability as well as its performance is severely affected when it is subjected to a severe environment. Corrosion of embedded steel bars is the main concern and is simultaneously influencing both the concrete durability and its strength. This corrosion leads the steel reinforcement to expand even up to seven times the original size. This develops a pressure zone on the concrete. This will develop cracks in the concrete and eventually leads to spalling of the concrete cover. In absence of concrete cover it exposes the structural steel reinforcement, which will propagate the corrosion activity. Corrosion results in decrease in bar diameter that will reduce the contact area between the steel bars and the surrounding concrete. It further leads to reduction in the bond strength. Reinforcement corrosion results into a bulky reaction product and it puts pressure in all directions on the surrounding concrete cover. This will initially develop cracksand eventually cause spalling of concrete. This spalling of concrete cover had lead to rise to possible injury, particularly in the case of cantilevers from high rise flats or bridges. The extensive corrosion of the steel bars results into mechanical weakening of the reinforced structure. And it will ultimately result into collapse of part or entire structure.

In marine environments and the associated de-icing salts causes degradation of the reinforced concrete structures due to chloride induced corrosion of the reinforcement, and this is a major problem in marine structures. Here also the corrosion process results into expansion and it cause concrete cracking and eventually spalling of concrete. It is important to make the assessment of residual strength as well as the residual life of steel, since they can be used as the main deciding factor for selecting an appropriate remedial measure to control the corrosion activity.

Loss of steel cross section and concrete integrity degrades the strength and serviceability of the structure. Corrosion in steel reinforcement is the main deteriorating mechanism and it is of high interest due to high remediation and repair costs.

Objective of Study

The objective of this research was to examine the adhesion of an epoxy coating to steel bars under wet, alkaline conditions. Simultaneously assess the effectiveness of locally produced materials in protecting the reinforcing steel against corrosion. With respect to time, resulting consequences on mechanical properties of steel and concrete are also evaluated.

2.LITERATUREREVIEW

P. C. S. Hayfield [1] investigated that there are different methods for providing protection against steel corrosion. Some of these methods can be mentioned to have noticeable results. Like the de-icing salts especially used on roadways, can work as effective technology. Then use platinum and other noble metals, along with titanium and niobium can be used as protective layer to avoid corrosion in steel. Based upon investigating different research work, it clear that the cathodic protection of steel bars in concrete is the well evident method to prevent from corrosion.

Vladimir Zivica [2] investigated the action of chloride solutions on carbonation of concrete and its influence of corrosion of reinforced steel. Also the natrium chloride solution is found to be more aggressive solution as compared to calcium and magnesium chloride solutions. Carbonation effect followed by chloride attack will lead to decrease in alkalinity of pore solution present in concrete. So the reinforcement becomes more prone of chloride attack. This affects the service life of structure. This very important from point of view of users of the concrete structure.

It is well known fact that steel corrosion is a very slow process. Infact when steel is embedded in concrete, then due to concrete cover, it will take even more time for initiation and further propagation of corrosion in steel bars. Even during severe corrosive exposure conditions this process will take more time. But for academic research a significant degree of corrosion is required to assess its effects on mechanical properties of reinforced concrete. That too the corrosion within short duration is not possible. Following concrete properties are difficult to assess during the intentional corrosion study: (1) decrease in load bearing capacity and loss of bond due corroded reinforcement in concrete members, (2) percentage addition of mineral admixtures which in turn are inhibiting the corrosion process (3) use of chemical coatings or alloy addition in reinforcing steel that acts against the corrosion and (4) effective electrochemical methods that lead to prevention of corrosion within steel.

C. Andrade [5]had reviewed past research based upon different subjects related to corrosion in steel. Along with that the service life and repair methods adopted for steel is also studied. Even though papers from last three decades were investigated still there are many factors unknown that are inhibiting corrosion in steel. Corrosion of Steel reinforcement in embedded concrete can be suppressed or slow down but the cost of method adapted must be investigated for its creditability and worthiness. So different methods investigated in paper can be studied further.

Shamsad Ahmad [6] had tried to use the impressed current technique to perform accelerated corrosion within reinforcing steel in concrete and this will help to study the above parameters. Depending upon the applied current intensity, degree of induced corrosion was assessed. Percentage reduction in mass was the defining factor showing the effect of applied current on rate of corrosion. Different alternative techniques used for inducing accelerated corrosion in reinforcing steel are also discussed in this paper.

3.METHODOLOGY

A. Materials used:

*Mild Steel:*It is one of the commonly used material of all metals and it is less expensive among other steels used in construction. Mild steel is found in almost every metal alloy. Mild steel bars are manufactured such that they have plain surface and have different diameters ranging from 6 to 50 mm. These bars are casted for long length upto 12-13 meters. They can be cut into small sections easily and quickly. Bars can be bend easily without any loss of strength or structural damage.Simultaneously they are hard, durable as well as weldable and are easily annealed.

*TMT Steel***:** TMT stands for 'Thermo Mechanically Treated' bars hot rolled from steel billets. TMT bars have much high yield point, but it is not having a well-defined value. The yield stress or characteristics stress is given by 0.2% proof stress. These bars possess ribs or deformations. Hence for Fe 500 their surface with the result their bond characteristic is improved. They are available in the grade of Fe415 and Fe500. TMT bars have very good bond with concrete than mild steel, so that they may be placed without end hook and with much smaller anchorage length, resulting in further saving in steel. Because of the high yield strength the quantities of steel require in RC work is reduced. Since the difference in its cost comparative to mild steel is marginal. So there is the reduction in the overall cost of RC construction.

*Epoxy Resin:*Corrosion of steel bars 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. 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. This coating acts as an electrical insulator for the reinforcing steel as it reduces flow of the corrosion current. Though bars completely coated with epoxy won't rust, their performance depends on the quality and integrityof the coating. With the improvement in adhesion property, epoxy coated rebar become the most economical method of corrosion protection of concrete construction. The corrosion protection properties of epoxy coating are always present.

*Cement:*Cement is the basic material in making a concrete. It is widely used in the construction from long years back. The Lime, Silica, Alumina and Iron oxide are the main ingredients used for manufacturing the cement. OPC is the most important type of cement. OPC is available in three grades as 33 grade, 43 grade and 53 grade. In current investigation concrete was prepared using Ordinary Portland cement (OPC) 53 grade. Although it is costlier than other low grade cement, but it offers 10-20 % saving in cement consumption along with many other benefits. One of the best advantage is the faster development of the strength.

Sand: Silica Sand is used predominantly due to its chemical purity and advantageous thermal properties. We use natural sand for making concrete. It has high hardness. Silica has a high fusion point above 1690^{0} degree Celsius. And it can be lowered dramatically by using Calcium, Sodium, Potassium, and Iron as a Fluxing agents. These elements are also used too drastically lower the sintering point of Silica. Due to the alkaline nature of these elements and due to their oxides, a drop of 99.8% is observed in Silica Sand, from 1700^{0}C to less than 1200^{0}C.

*Coarse Aggregate:*Maximum 20 mm size coarse aggregates are used. It was observed that coarse aggregate is consisting of naturally occurring materials such as gravel, or it may be resulting product from the crushing of parent rock so as to include natural rock, expanded clays, shales and slags. Other approved inert materials with similar characteristics and which are having hard, strong, durable particles, conforming to the specific requirements may be present in coarse aggregates.

*Salt (Nacl solution 5%):*5% sodium chloride (NaCl) by the weight of water is used to intentionally corrode the steel reinforcement.

B. Experimental Investigation:

Eighteen concrete blocks with dimensions (15 × 15 cm) provided with central steel bar were cast and tested after 28 days to demonstrate the effect of the protective materials on the bond strength. Cubical Specimens with concentric steel bar were 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 was drilled on one end of the bar for electrical connection. Bottom cover was 20mm.

Different diameter rebars of mild steel and TMT were used- 16 mm, 12 mm and 10 mm dia.

Rebar used are of 1meter 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.

*Set up for Corrosion:*After the 18 pull-out specimens casted and cured, 36 specimens were subjected to accelerate corrosion by placing them in the accelerated corrosion tanks. The accelerated corrosion setup consisted of 60 cm diameter plastic tank. Electrolytic solution is made from 5% sodium chloride taken as weight of water. A steel mesh was placed around the specimen. The concrete cubes with concentric rebar assembly were placed in the accelerated corrosion tank. It was partially immersed i.e. up to two-third of its height in the electrolytic solution. To eliminate any change in the concentration of the NaCl and pH of the solution every week, the electrolyte solution was replaced. Then 12V DC supply was passed through the solution to corrode the rebar.

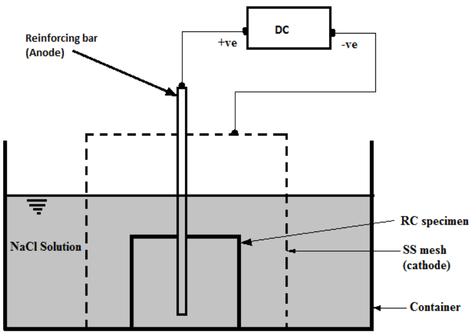

Figure 1 Schematic Representation of the Device for Accelerated Corrosion.

The specimen bars were connected to electrical wires by clips then connected to 12 V power supply. The impressed current was passed through the specimen. The set-up consisted of DC power source, along with that a counter electrode, and theelectrolytic solution. The positive terminal of the DC power source was connected to the steel bars (anode) and the negative terminal was connected to the wire mesh (cathode). The current was passed through counter electrode to rebars that were embedded in concrete. This was done with help of sodium chloride solution .

Figure 2: Laboratory set up for Accelerated Corrosion for Epoxy Coated Rebar

C. Tests on cement

- Standard Consistency of Cement:The percentage of water required to produce a paste of standard of consistency is 32.5%.
- Initial & final setting time:

Initial setting time	Final setting time
117 min.	372 min.

- Compressive strength cement :

3 days (N/mm^2)	7 days (N/mm^2)	28days (N/mm^2)
26.35	40.75	55.01

D. Tests on Fine aggregates

- Moisture content : The average moisture content of fine aggregates are tested and found to be 0.77
- Fineness modulus of fine aggregate by dry sieving : It is found to be 2.94

E. Test on Coarse aggregates

- Moisture content : The average moisture content of fine aggregates are tested and found to be 0.33
- Fineness modulus of fine aggregate by dry sieving : It is found to be 4.77
- Crushing value of coarse aggregate : The average crushing value is 26.60

F. Mix Design for M-20 Grade of Concrete

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) …… (IS: 10262-1982, Table 1)
=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

As per IS: 10262-1982, table 4, pp. 9.

For 12.5mm size of aggregate water content per $m^3$of concrete in kg=200kg and Sand as % of total aggregate as 40%

To Know Cement Content
W/c = 0.50
c = 200/0.50
= 400kg …… (IS: 456-2000, Table 5, pp. 20)

Naturally entrained air is taken as volume of concrete 3% as per IS: 10262-1982, table 3 for 12mm size.
As per IS: 10262-1982, equation 3.5.1, pp. 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 in kg/m^3 of concrete.
C = mass of cement in kg/m^3 of concrete.
Sc = Specific gravity of cement.
P = It is the ratio of fine aggregate to total aggregate taken as absolute volume.
fa, ca = total mass of fine aggregate and course aggregate in kg/m^3.
Sfa, Sca = Specific gravity of saturated surface dry fine aggregate and course 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/m^3
Similarly,
Ca = 1071.70kg/m^3
We get,

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

G. Test on Concrete
W/C Ratio =0.5
Proportion(C: FA: CA) = 1:1.67:2.67
Size = (150 x 150 x 150) mm

Table No.1: Compressive strength of concrete

Sr. No.	Age of Cube (Day)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	3	10.75	10.07
2	3	10.57	
3	3	8.88	
4	7	11.95	13.39
5	7	13.11	
6	7	15.11	
7	28	20.25	20.23
8	28	20.13	
9	28	20.31	

Pull-out Test on Specimen: It is prepared by pouring M20 concrete in the cube mould having the internal dimensions 150×150×150 mm. Place a mild steel/ TMT bar at center of specimen before concrete sets and becomes hard. The specimens are kept immersed in water for 28 days for proper curing and taken out from water at time of testing. 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 obtained by using the formula:

Ʈ= F/ (L*S)WhereƮ= Bond Stress in MPa F= Applied pulling load in kN ; S= Perimeter of rebar L= Embedded length of rebar= 130 mm

4. RESULTS

The defining criteria in this study was concrete specimen were prepared along with concentric mild steel and TMT rebar of different diameters 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 pull-out 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 after the 21 days of curing for the 7 days and observation are taken.

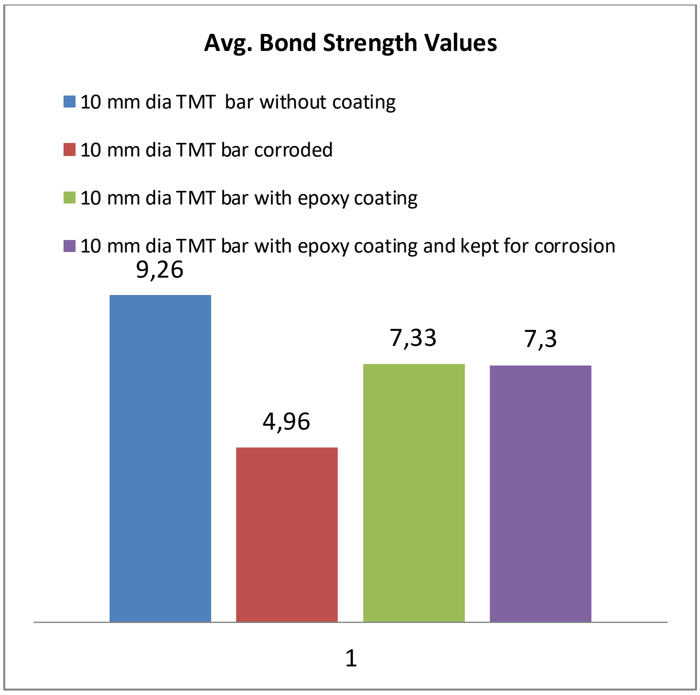

Chart 1. Comparison of Avg Bond Strength of 10 mm dia TMT

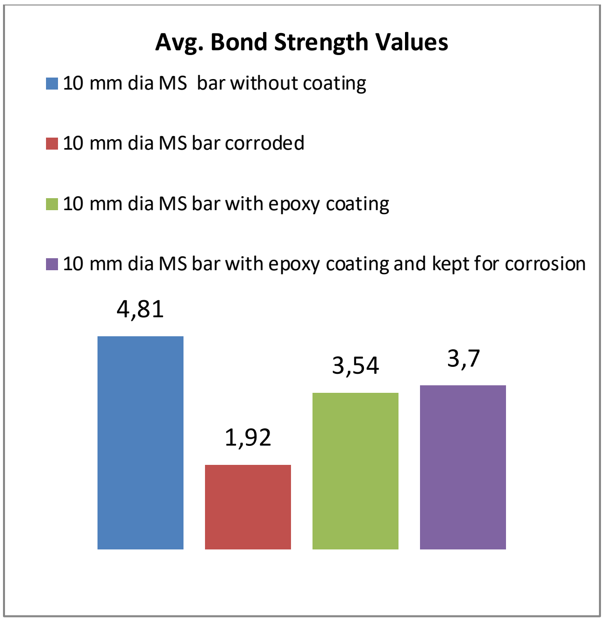

Chart 2. Comparison of Avg Bond Strength of 10 mm dia MS

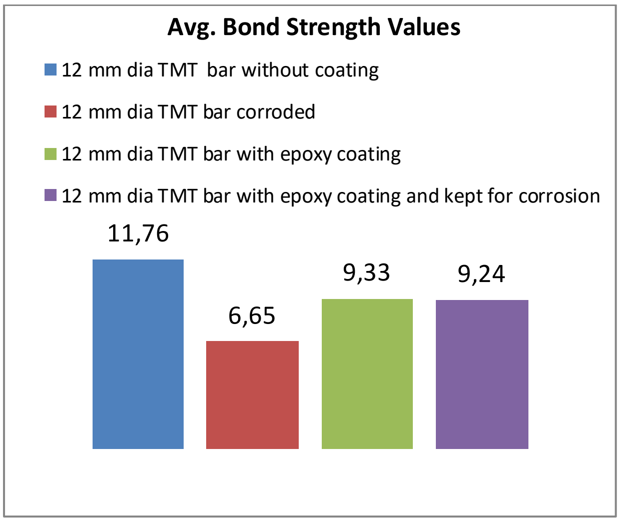

Chart 3. Comparison of Avg Bond Strength of 12 mm dia TMT

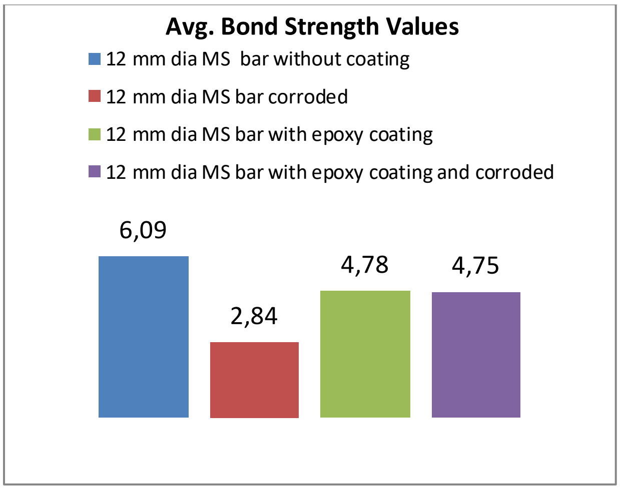

Chart 4. Comparison of Avg Bond Strength of 12 mm dia MS

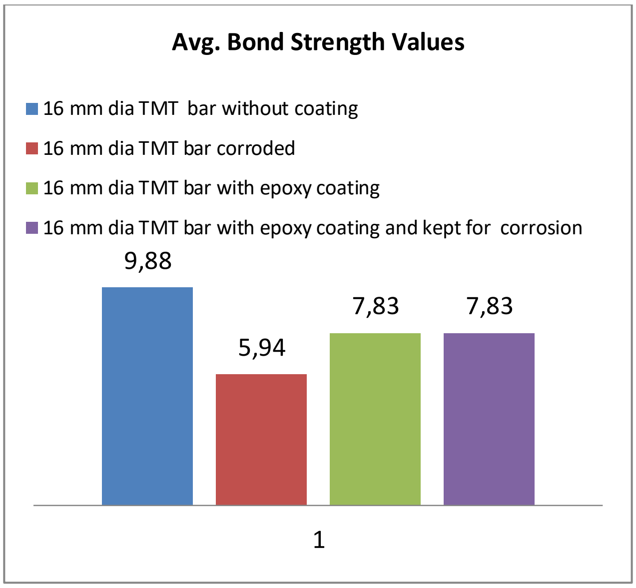

Chart 5. Comparison of Avg Bond Strength of 16 mm dia TMT

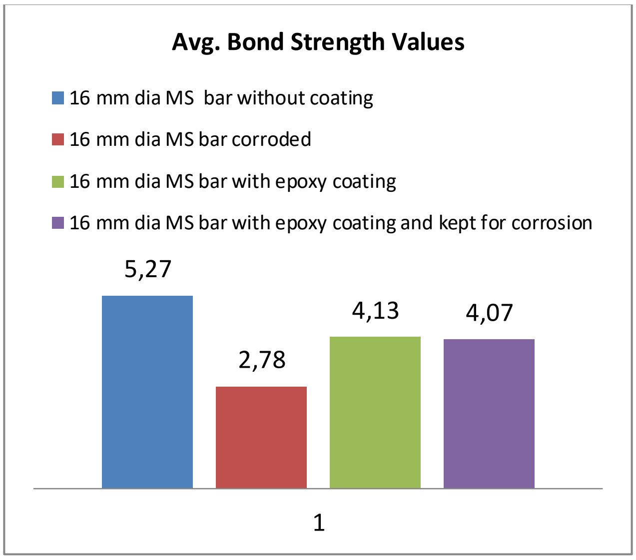

Chart 6. Comparison of Avg. Bond Strength of 16 mm dia MS

5. DISCUSSION

Under the accelerated corrosion test, the epoxy-coated bars showed the lowest current readings during the whole period of the immersion time as compared to the regular carbon steel bars. In case of uncoated bar subjected to accelerated corrosion following observations were 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 was achieved by using Epoxy coated rebar.

6. CONCLUSIONS

- 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% to54% 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.

ACKNOWLEDGEMENT

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