Study on the efficiency of CFRP and GFRP in corrosion resistance of rebar embedded in concrete

M Ananthkumar¹, K M Mini¹, C Prakash¹, S Vishnu Sharma¹ and A C Bharath Krishnaa¹
Department of Civil Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Tamil Nadu, India
Email: m_ananthkumar@cb.amrita.edu

Abstract: Efficiency of composite materials like carbon fibre reinforced polymer (CFRP) and Glass Fibre Reinforced Polymer (GFRP) in controlling rebar corrosion is not studied much. In the present study, cylinders of size 300mm height and 100 mm diameter were casted by using CFRP as a wrap and GFRP in powdered form as an admixture in concrete. Anti-corrosive rubber coating is applied all over the rebar. The concrete cylinders are subjected to accelerated corrosion using 0.5M HCl and 3% NaCl solution for a period of 60 days. The corrosion rate was calculated at regular intervals using Half-cell potential, Linear Polarisation Resistance and Tafel plot measurements. The corrosion resistance of all the specimens are compared and the results have shown that both CFRP and GFRP performed well in corrosion resistance at varying levels. The appropriate protection material from corrosion is also proposed.

1. INTRODUCTION

Reinforced concrete being a versatile material in building construction is mainly damaged due to corrosion of rebar by the ingress of chlorides, acids, sulphates and carbon dioxide. Many countries are investing billions of dollars for corrosion resistance. Hence it is necessary to find an economical way to control the corrosion of rebar in concrete. In the present study, the efficiency of composite materials such as Carbon Fibre Reinforced Polymers (CFRP), Glass Fiber Reinforced polymers (GFRP) in resisting the corrosion of rebar was studied. Corrosion is the deterioration of metals. It is an electro-chemical process by which metal is deteriorated due to oxidation. Application of composite materials are also widening in durability enhancement of concrete structures. The reinforcement of GPC embedded in the low-calcium fly ashes did not show signs of corrosion products, and this is in agreement with the electro-chemical analysis (corrosion rates)[1]. Blended fly ash and slag geo-polymer concrete has higher age factor than in OPC concrete indicating improved resistance to chloride ingress with time [5]. The corrosion can be controlled by applying protective coatings to rebar or concrete. The corrosion resistance of Strontium phosphate coating on steel rebar is better than barium and Epoxy when compared in different medium [18]. The resistance of chloride permeability of both geopolymers-based coatings system was superior to the concrete without coating [11]. The coated concrete specimens exhibited higher electrical resistivity compared to the concretes without coatings [12]. The protective coatings used here are anti-corrosive rubber coating to rebar, CFRP wraps (Bi-Directional Twill type) to concrete cylinders.

Another way to control corrosion is by adding admixtures to concrete where in GFRP powder (figure 1) admixture was used here to improve its corrosion inhibition property. CFRP laminates are found to be successfully applying cathodic protection when used as anodes in electrochemical protection [8]. Thus, this eliminated the need for using any external anodes for the application of cathodic protection.
[2]. The need for recalibrations to be used for geopolymer-based corroding systems apart from the conventional classification while assessing the passivity of samples [3]. Cracks of micro size were noticed on the steel fibre reinforced Geopolymer concrete specimens [4, 6]. The introduction of Calcium nitrate caused a shift in the equilibrium potentials anodically with the formation of a passivation film of iron(III) hydroxide on the rebar [17]. Sulphate corrosion had slight effect on the mechanical performance of the two FRP materials, thus verifying their relatively high durability [10]. A reduction in hoop strength was observed in the GFRP and BFRP [11] (23% and 39% loss respectively after 6 months) whereas the CFRP reduction is only 8%. Environmental effects on Young’s modulus of FRP are insignificant [7]. The addition of PVAFRGC helped reduce the effects of corrosion [13]. The average percentage of steel mass loss of 8.5% was observed and in case of control specimens, the values reduced to 7% and 5.5% for the specimens with 25 and 50 mm PVAFRGC repair layers respectively [15]. The Fe2+ ions of rebar tend to maintain neutrality but they migrate through water present in the concrete to the cathodic sites and reacts with OH− and forms FeOH or rust [16]. This FeOH further reacts with oxygen to form a brown colored Ferric oxide which occupies greater volume than steel. Due to this spalling of concrete cover occurs.

Figure 1 GFRP powder and CFRP wrap

Fiber Reinforced Polymers (FRP) can resist abrasion and corrosion. The steel fibre reinforced geopolymer concrete specimens proved to resist chloride attack better than a control specimen with geopolymer concrete specimen [9]. Fibers contributes to the strength and resins contribute to the corrosion resistance. FRP used in corrosion are Glass Fibre Reinforced Polymer and Carbon Fibre Reinforced Polymer. These FRP’s are adhesively bonded to the specimen using adhesives such as Epoxy. FRPs can resist electrochemical corrosion and avoids deterioration in aggressive environments such as acids, alkalis, salts etc.

2. MATERIALS USED

2.1. Coating materials
Coating materials are used to control the corrosion. It doesn’t allow the water to penetrate through them. It creates a barrier between metal surface and the corrosive medium. In this experiment the coating materials used are Asian Chlorinated Rubber High Build Coating which was bought at local paint shop. Another wrapping used was Bi-directional twill type CFRP, which is wrapped around the concrete specimen. This CFRP was bought from VRUKSHA COMPOSITES, Chennai.

2.2. Admixtures in Concrete
Admixtures are generally used to improve the performance of concrete. In this experiment the admixture used is Glass Fibre Reinforced Polymer. The amount of GFRP mixed is 2% to the weight
of cement. It prevents the water to flow through the concrete and also increases the bond between rebar and concrete. This GFRP was bought from VRUKSHA COMPOSITES, Chennai.

2.3. Solutions for Corrosive environment
The process of corrosion of steel was accelerated by providing a corrosive environment by using a solution 3% NaCl and 0.5 M HCl.

2.4. Adhesive for wrapping CFRP
EPOXY resins were used as adhesives for wrapping the CFRP coating over the concrete specimens.

3. EXPERIMENTAL PROGRAM
The experimentation has been carried out in the following steps

3.1. Casting of RC specimen
Cylindrical specimens of 100 mm diameter and 300 mm height were casted with concentrically embedded rebar of 12 mm diameter. The cylinders were casted with M20 design mix. 12 Cylinders were casted for inducing corrosion and 1 specimen for compressive strength. The cement used for casting is Ordinary Portland Cement (OPC). The sand used is River sand passing through 4.5 mm sieve. The coarse aggregate used of size 20 mm. Steel Rebar used of grade Fe415 is of length 400mm protruding 130 mm outwards. Water/cement ratio is 0.44. Two specimens were prepared for each type one for HCl solution and the other for NaCl solution. The types of concrete specimen casted were control specimen, specimen with anti corrosive rubber coating and cylindrical specimen wrapped with CFRP using Epoxy and concrete mixed with GFRP powder and wrapped with CFRP using Epoxy. All the rebars were coated with anti-corrosive rubber coatings and protective layers, which were applied after curing for 28 days.

3.2. Preparation of 0.5M HCl and 3%NaCl solution
- 0.9576 litre of water was taken in a test tube and mixed with 0.0424 litre of concentrated HCL to make 0.5M HCl.
- 3 mg of NaCl was dissolved in 100 ml of water to make a 3% NaCl solution.

3.3. Inducing initial corrosion
On completion of curing period the cylindrical specimens were induced to accelerated corrosion. Accelerated corrosion was induced by completely immersing each set of specimens in 0.5M HCl and 3% NaCl solution. Due to accelerated corrosion the protective passivating layer or oxide layer is destroyed by the chlorine ions.

3.4. Electrochemical Experiments
All the tests were carried out in an Air Conditioned room at 20° centigrade. The tests that conducted are Open Circuit Potential (OCP) designated as $E_{corr}$, Linear Polarisation Resistance (LPR) designated as $R_p$, and Tafel plot using SP: 300 Biologic EIS instrument and Open circuit Potential using Elcometer. The pH of the HCl and NaCl are measured using pH paper and color chart, because to occur corrosion pH is the main parameter. So measuring pH at periodic intervals is necessary. A three electrode setup is must to carry out electrochemical tests. The three electrode setup consists of Saturated Calomel electrode as reference electrode because it has a pre-determined voltage which helps in measuring the voltage of the specimen. A steel mesh is used as counter electrode and the rebar itself is a working electrode. While conducting experiment the specimens are partially immersed in water up to three fourth of the height of the specimen. Both the reference electrode and counter electrode are immersed in water. The Experimental setup is shown in figure 2
The open circuit potential was calculated by stabilizing it until the deviation of the $E_{\text{corr}}$ value is not varying for a 60s period of time. The input parameters to conduct OCP were entered into the software. The experiment was run until a stabilized value was arrived. A graph was drawn with time(s) on X-Axis and potential value $E_{\text{we}}(v)$ on Y-Axis for every 30 sec time interval until the a constant value was obtained.

The most used technique to evaluate corrosion current $I_{\text{corr}}$ is Linear Polarisation resistance. It is also used to calculate rate of corrosion using Stern-Geary equation:

$$I_{\text{corr}} = \frac{\beta_a \times \beta_c}{2.3 \times R_p \times (\beta_a + \beta_c)}$$

$\beta_a$ and $\beta_c$ are the anodic and cathodic Tafel slopes. $R_p$ can be obtained from the slope of polarisation curve $R_p = \left(\frac{\Delta E}{\Delta I}\right)_{AE-Q^0}$

In linear polarisation resistance the value of $\Delta E$ was limited to $\pm 20$ mV. The value of B was found to be 26 and 52 mV for active and passive state. The rest period $t_R$ was set for 30 seconds and $\Delta E/\Delta T$ was set to 10 mV/s. A graph was plotted between $I$(mA) VS $E_{\text{we}}$(V). The corrosion current $I_{\text{corr}}$ was calculated for the corresponding $E_{\text{corr}}$ value. Higher the value of $R_p$, higher was the ability to resist corrosion. Another type of technique is the Tafel plot which can be used for a wide range of $\Delta E$ ranging at $\pm 200$ mV. In this technique the rate of corrosion can be calculated directly by using the equation

$$\text{Corrosion rate(CR)} = \frac{I_{\text{corr}} \times K \times EW}{d \times A}$$

Where $K$= constants for the units of corrosion rate= 3272 mmpy.
- $d$= density in g/cm$^3$= 7.86 g/cm$^3$.
- $A$= surface area of the steel rod.
- $EW$= equivalent weight in g/equivalent= 27.92 g/equivalent.
- $I_{\text{corr}}$= Corrosion Current

A graph is drawn between log I VS E in order to calculate the corrosion current value. Tafel Plot is a destructive type of process and cannot be performed many times. In elcometer the half-cell potential value can be directly obtained.
4. RESULTS AND DISCUSSION

In the present study all the reinforced concrete specimens were subjected to accelerated corrosion by creating marine and acidic environment by means of 3% NaCl and 0.5M HCl respectively. The specimens are protected with CFRP wraps, GFRP mixed in concrete and wrapped with CFRP, anti-corrosive rubber coating. The influence of these protective layers was studied by monitoring various parameters like Half Cell Potential, Linear Polarisation resistance and Tafel Plot for every 15 days interval up to 60 days. The Half Cell potential values are shown in table 1.

| Specimen | NaCl Solution (15 days) $E_{corr}$ (mV) | HCl Solution (15 days) $E_{corr}$ (mV) |
|----------|--------------------------------------|--------------------------------------|
| CS       | -239                                 | -589                                 |
| EPOXY    | -550                                 | -581                                 |
| CFRP     | -576                                 | -644                                 |
| GFRP     | -556                                 | -678                                 |

The Half Cell Potential values of all the specimens after inducing corrosion i.e., after 60 days are shown in table 2.

| Specimen | NaCl Solution (60 days) $E_{corr}$ (mV) | HCl Solution (60 days) $E_{corr}$ (mV) |
|----------|--------------------------------------|--------------------------------------|
| CS       | -595                                 | -590                                 |
| EPOXY    | -539                                 | -575                                 |
| CFRP     | -580                                 | -595                                 |
| GFRP     | -553                                 | -595                                 |

From the above results, it is observed that the Half Cell potential values are varying. From comparison with the standard values it is observed that more the negative value corrosion is more. Hence So half cell potential value alone is not found to be valid for the calculation of corrosion rate. The stabilization of Half Cell Potential with the mean time is explained in the Figures 3 to 10.
From the above graphs it is clear that there is not much variation in the the Half Cell potential values and is almost constant for all the specimens. The Half cell Potential of Control specimen placed in NaCl solution had a great difference in variation because of the disturbance and impurities present in the electrolyte solution. The Half Cell Potential value can also be found by use of Elcometer, in which the experiment consists of a copper sulphate (CuSO$_4$) electrode and a working electrode (rebar) which is connected to multimeter. The copper sulphate electrode is placed over the surface of the concrete and corresponding half cell potential values were recorded from the multimeter. The half cell potential values observed from elcometer is shown in table 3.
Table 3 Initial and Final reading of Elcometer

| Type of specimen | Initial Readings | Final Readings |
|------------------|------------------|----------------|
|                  | NaCl solution mV | HCl solution mV | NaCl solution mV | HCl solution mV |
| Controlled Specimen | -280            | -290            | -650            | -750            |
| Epoxy coated     | -145            | -112            | -670            | -700            |
| CFRP             | -120            | -102            | -480            | -723            |
| GFRP             | -120            | -130            | -680            | -580            |

From the above table it is observed that the Half Cell Potential values of each specimen fell under same category i.e., under 90%. The rate of corrosion was be calculated by

Corrosion rate(CR)= \( I_{corr} \cdot K \cdot E_W / d \cdot A \)

The initial and final corrosion rates of all the specimens using LPR constants are shown in table 4 and 5 below

Table 4 Corrosion rates of NaCl samples using LPR Constants

| Type of specimen | Corrosion rate (15days) (mmpy) | Corrosion rate (60 days) (mmpy) |
|------------------|---------------------------------|---------------------------------|
| Controlled Specimen | 0.035098                      | 0.049584                        |
| Epoxy coated     | 0.021973                      | 0.044389                        |
| CFRP             | 0.012168                      | 0.024292                        |
| GFRP             | 0.013254                      | 0.023751                        |

From the above table the initial maximum corrosion rate was observed in EPOXY coated sample and from the samples kept in NaCl solution for 60 days, the maximum corrosion rate was observed in the EPOXY coated and the minimum corrosion was observed in the GFRP sample. The GFRP sample had resisted the corrosion to a minimum. The CFRP specimen and GFRP sample also performed well but the GFRP sample showed better results.

Table 5 Corrosion rates of HCl Samples using LPR constants

| Type of specimen | Corrosion rate(15) | Corrosion rate(60) |
|------------------|--------------------|--------------------|
| Controlled Specimen | 0.032018         | 0.037044           |
| Epoxy coated     | 0.022863          | 0.023747           |
| CFRP             | 0.013264          | 0.017041           |
| GFRP             | 0.014267          | 0.014059           |

From the above table 5 the initial maximum corrosion was observed in EPOXY coated sample and the minimum corrosion was observed in CFRP sample since, the specimens were casted at different dates and the samples had pre corroded even before the samples were kept in solution. The minimum corrosion was observed in the GFRP sample. Both CFRP and GFRP have resisted corrosion to a good extent with a slight difference. The slight difference is due to the impurities in the electrolyte solution and the environmental disturbances which were caused during the execution of the experiment. Graphs were plotted between I(mA) VS Ewe(V).
Figures 11 to 14 shows the corrosion current that has been calculated for the set of samples from the recorded $R_p$ value at 15 and 60 days. The graphs were plotted between corrosion current densities and corrosion potential, it is observed from the graphs that there is a consistent increase along the plot. It is also observed that there is a formation of a layer of iron oxide around the rebar.

The initial and final corrosion rates of all the specimens using Tafel constants at 15 and 60 days are shown in table 6 and 7 below.

| Type of specimen | Corrosion rate (15) (mmpy) | Corrosion rate (60) (mmpy) |
|------------------|---------------------------|---------------------------|
| Controlled Specimen | 0.045697 | 0.042619 |
| Epoxy coated | 0.025457 | 0.032192 |
| CFRP | 0.014408 | 0.016134 |
| GFRP | 0.014357 | 0.018773 |

From the above table 6 the initial maximum corrosion rate was observed in Epoxy coated sample and minimum corrosion was observed in the Control Specimen. The samples were placed in NaCl solution for 60 days and the maximum corrosion was observed in the control specimen and minimum corrosion was observed in the CFRP sample. The control specimen had failed to resist corrosion as the protective layer around the rebar had completely eroded. The CFRP wrapped around the concrete,
resisted the penetration of water. The GFRP specimen also resisted the corrosion to a good extent.

| Type of specimen | Corrosion rate (15) (mmpy) | Corrosion rate (60) (mmpy) |
|------------------|-----------------------------|----------------------------|
| Controlled Specimen | 0.049785 | 0.046952 |
| Epoxy coated | 0.030347 | 0.031859 |
| CFRP | 0.016726 | 0.017416 |
| GFRP | 0.019435 | 0.019533 |

From table 7, the initial maximum corrosion rate was observed in the control specimen and minimum corrosion was observed in the CFRP sample. The samples were placed in HCl solution for 60 days and the maximum corrosion was observed in the control specimen and minimum corrosion was observed in the CFRP sample. The control specimen had failed to resist corrosion as the protective layer around the rebar had completely eroded. The CFRP and GFRP proved to have good corrosion resistance properties.

From the above figures 15-18, the anodic Tafel constants and cathodic Tafel constants were calculated by the slopes of anodic and cathodic branches of the Tafel curve, which is also known as Tafel extrapolation a method, widely used for the calculation corrosion current. The corrosion current densities of samples were calculated using values of B= 26 were found to be lower, when compared to the corrosion current densities calculated using Tafel Extrapolation, since the mean $R_p$ value recorded for each specimen at regular intervals is not representative of average $R_p$ value of all specimens.
5. CONCLUSION

Efficiency of CFRP wrapped concrete and GFRP admixture modified Concrete with CFRP wrapping in resisting the corrosion of steel rebar embedded in concrete cylinders are effectively studied and compared in this work. The amount of GFRP added in concrete should be in the range of 1.5% to 2.5% of the total weight of concrete. From the electrochemical measurement under accelerated corrosion, it is observed that the high alkalinity introduced by composites such as CFRP wrapping and GFRP powder improved the resistance for ingress of corrosion causing agents. Reductions in the corrosion potential were observed, which indicates that steel rebars were under the process of corrosion. In case of CFRP and GFRP specimens the corrosion potential values have a very minimum risk to corrosion. The corrosion rates calculated using Tafel constants and LPR constants are limited for CFRP and GFRP when compared to the other specimens and hence prove to validate the above discussion. An error factor of less than 2 is obtained with the help of Stern-Geary equation for the calculation of corrosion current.

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