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# Impressed current cathodic protection of rebar in concrete using Carbon FRP laminate

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## HIGHLIGHTS

- CFRP laminates can be used as anode for applying ICCP to rebar.
- In ICCP, bond stress decreases with increase in protection current density.
- Corrosion rate decreases, with increase in protection current density.
- The most appropriate corrosion protection current density for RC is suggested.

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## ABSTRACT

Carbon FRP can be used as anode in impressed current cathodic protection of rebar in concrete. Although, ICCP reduces mass loss in rebar due to corrosion, it reduces bond, too. Most appropriate protection current density is investigated that induces lowest mass loss with highest bond stress. ICCP was applied with different protection current densities to rebar in concrete, pre-corroded to three corrosion levels. CFRP was bonded to concrete surface using conductive adhesive. Protected specimens were exposed to corrosive environment. Effectiveness of ICCP was evaluated by half-cell potential, LPR, bond stress and mass loss. The appropriate protection current density is proposed.

## 1. Introduction

One of the major reasons for causing loss in the service life of reinforced concrete (RC) structures is corrosion of reinforcing bars (rebar). Concrete surrounding rebar develops a strong bond with it to achieve intended structural performance. As concrete is highly alkaline in nature with pH value ranging between 11 and 13 [1], forms a passive layer surrounding rebar, which protects rebar from corrosion. The alkaline passive layer consisting of soluble calcium, potassium and sodium oxides is dense and prevents corrosion of rebar if maintained properly. Chloride attack and carbonation are the two main factors responsible for corrosion of rebar in concrete [1]. Corrosion products formed on the surface of rebar are 6–7 times voluminous than original metal [1]. These voluminous corrosion products exert pressure on the surrounding concrete and initiates crack formation at concrete-rebar interface. With increase in corrosion level, these cracks propagate, widen and eventually cause spalling of concrete cover. The rebar gets directly exposed to the environment that further aggravates corrosion process. Corrosion of rebar results in reducing the cross-sectional area of rebar. It also reduces the bond between steel and concrete. It has been also reported by researchers that mechanical properties of rebar get adversely affected due to corrosion [2,3].

Use of Fiber reinforced polymer (FRP) composite materials for repairing corrosion damaged structures have become very popular since couple of decades. FRP composite materials are manufactured by embedding strong and stiff fibers in polymer matrix. The resulting composite has high strength to weight ratio, high stiffness to weight ratio, and better resistance to environmental weathering. Glass FRP (GFRP), Carbon FRP (CFRP) and Aramid FRP (AFRP) are commonly used FRP composites for strengthening of RC structures. Unlike other repairing techniques, use of FRP does

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not apply any additional load on the structure. It has very low maintenance and does not create larger stress concentration in existing structures. The durability of FRP strengthened structures has been experimentally checked and found to perform well in various environmental conditions [4,5]. The flexural strength and stiffness of FRP strengthened beams are also found to have increased [6,7]. The shear strength of structural members strengthened with FRP have been found to increase to a level where it almost acts as an undamaged beam with enhanced crack resistance [8,9]. Seismic performance of structural members including beam column joints has also been found to be improved by strengthening with FRP [10–12]. FRP confinement provides strong hold against thrust applied by rust imparting solidity to concrete thereby avoiding spalling of concrete along with increased load carrying capacity. Thus, enhancement of structural performance is well established with application of FRP to damaged RC structures. Researchers have investigated the corrosion activity in FRP strengthened RC structures. FRP wrapped around concrete surface creates a barrier layer to diffusion of moisture and oxygen into the concrete which leads to decreased corrosion rate [13–15]. Some researchers have studied the galvanic corrosion activity of mild steel coupled to carbon composite in different environments like concrete, deicing solution and seawater and found that the corrosion rate of steel increases manifold when it is coupled with carbon composite [16–18].

Cathodic protection is one of the many available corrosion protection methods. It is based on the principle of connecting an external anode to the metal to be protected to pass an electrical direct current so that all areas of the metal become cathodic and therefore do not corrode. Cathodic protection can be achieved in two ways; by sacrificial anode cathodic protection or by impressed current cathodic protection (ICCP). In ICCP, an external anode is connected to the rebar to be protected and direct negative current is passed to the rebar so that the rebar surface becomes cathode and does not corrode. For cathodic protection, various types of anodes have been used by researchers, such as conductive paints, catalysed titanium, conductive overlay such as thermally sprayed zinc, discrete probe anode [19,20]. ICCP can stop corrosion in high chloride levels also and it increases the pH around rebar up to passivation [21]. Federal Highway Administration, USA states that cathodic protection is the only method which decelerates corrosion in chloride contaminated RC structures irrespective of amount of chlorides [22].

Cathodic protection system is designed based on number of parameters. One of the most important design parameters is cathodic protection current density to be applied to the rebar. Various standard code of practices have specified cathodic protection current densities. BSEN 12696 suggested it to be 2–20 $mA/m^2$, while BS 7261-1 has specified it to be 5–20 $mA/m^2$, to stop any further rebar corrosion [23,24]. The demand of protection current density varies depending upon type of structure, its functionality and exposure condition. If higher current densities are applied than the required quantity for a longer period, the loss of bond between rebar and concrete occurs. This happens due to excessive evolution of hydrogen gas (Hydrogen embrittlement) at the cathode that is rebar surface [25,26]. Therefore, to avoid bond loss due to application of excessive current density, it is imperative to provide appropriate current density that protects rebar against corrosion without causing much loss of bond [27].

Carbon FRP is found to be electrically conductive and therefore can be used as anode for applying cathodic protection to the rebar in CFRP strengthened RC structures [28–31]. If CFRP is made anode in Cathodic protection system, in addition to strengthening, corrosion protection can also be achieved. Even though many researchers have established the use of CFRP as an anode in ICCP system, the optimum protection current density to be provided against corrosion is not reported. The present study emphasizes on investigating appropriate protection current density to be applied to the RC structures that are corrosion damaged at different levels. These protection current density values shall be sufficient to protect rebar against corrosion as well as to retain the bond between rebar and concrete. For this, rectangular concrete specimens were prepared and corroded to achieve different levels/percentages of corrosion. Initial corrosion was induced by impressing direct anodic current to rebar. CFRP laminates were bonded to those specimens to simulate the CFRP strengthened RC structure. CFRP bonded specimens were further exposed to corrosive environment for a definite period, albeit by applying ICCP. Different corrosion protection densities were applied to each corrosion level. Corrosion of protected specimen against unprotected specimen was monitored throughout the period of exposure. The monitoring was carried out by studying non-destructive as well as destructive parameters and the most appropriate protection density is proposed for each level of corrosion.

## 2. Experimental program

The experimentation has been carried out in the following steps-

- Casting of RC specimens
- Inducing initial corrosion
- Applying surface bonded CFRP laminates to pre-corroded specimens
- Protecting precorroded, CFRP bonded specimens by applying ICCP while the specimens were further subjected to corrosion by exposing to salt spray
- Corrosion monitoring
- Destructive testing

### 2.1. Casting of RC specimens

Rectangular concrete specimens of 100 mm × 100 mm cross-section and 200 mm height were cast with concentrically embedded rebar of 12 mm diameter. The concrete cover to the rebar was maintained at 44 mm on sides and bottom. M45 grade of concrete (characteristic compressive strength of concrete is 45 MPa) was used [32]. Concrete was made using Ordinary Portland Cement of Compressive strength 53 MPa (OPC Grade 53) [33], natural river sand as fine aggregates and coarse aggregates ranging from 4.75 mm to 20 mm. Concrete mix design was carried out in accordance to IS 10262 [34]. Steel rebar of yield strength 500 MPa (IS Fe500 grade) was used [35]. The rebar used were corrosion free. Rebar were kept in oil immediately after rolling, to avoid its contact with air and moisture thereby maintaining zero corrosion. Rebar were cleaned with acetone to remove oil from the surface just before embedding into concrete. The weight of each rebar was measured up to the accuracy of 1 gram. The total length of each rebar was 316 mm. Teflon (Polytetrafluoroethylene) tape was wrapped around rebar at bottom edge and at the interface with the concrete top face to serve as bond breaker. The protruded part of the rebar was epoxy coated to protect from corrosion. Thus, only the middle 130 mm embedded length of rebar was subjected to corrosion. 3 mm wide and 15 mm deep groove was made at outer end of rebar to accommodate copper stud for electrical connections. The dimensions and details of the specimen are shown in Fig. 1(a). A special moulding system was fabricated for casting the RC specimens as shown in Fig. 1(b) that enabled maintain the equal concrete cover from all sides. The RC specimens were moist cured for 28 days.