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Cathodic Protection of Corroded Pre-stressing Tendon by CFRP Sheets

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Abstract— **Reinforced concrete is one of the most commonly used construction materials in civil engineering but its durability problems have been obsessing people. The worst of these problems is caused by corrosion of steel in concrete which includes early deterioration of concrete infrastructures.**

Cathodic Protection is a reduction/elimination of corrosion by making the material a cathode by impressing a DC current. A new development in repair and rehabilitation of R.C structures is the use of carbon fibre reinforced polymers (CFRP) which provide a barrier layer that is expected to impede further corrosion of steel and prevents dislodging of concrete cover.

The present paper describes the protection of the strand achieved by using surface bonded carbon FRP. The electrically conductive carbon fibre is used as anode while the pre-stressing tendon is used as cathode in the present active protection.

Specimens were exposed to highly corrosive environment for specified time. It is observed that the active protection technique is very effective in retarding the corrosion of strand.

Index Terms— **Active Protection, F RP, Impressed Current, Prestressing Tendons.**

I. INTRODUCTION

Reinforced concrete (RC) has been developed and applied extensively in the twentieth century. It combines the good compressive strength of concrete with the tensile strength of steel and has proven to be successful in terms of both structural performance and durability. However, one major flaw, namely its susceptibility to environmental attack, can severely reduce the strength and life of these structures. Corrosion is defined as the destruction or deterioration of a material because of its reaction with environment. This leads to reduction in strength and reliability of structures. Once it starts, it is almost impossible to stop the process until eventually the safety, stability and design service life are all drastically reduced with time.

Review of recent research work indicates that little work has been done in the area of active protection of corroded pre-stressing tendon by CFRP sheets. [1] carried out active protection of the steel embedded in concrete that is treated with surface-bonded carbon FRP, [2] illustrated the findings of an experimental investigation carried out on six slab specimens for evaluating the performance of concentrically placed rebar of 25mm diameter in chloride contaminated concrete at three different stages of corrosion, [3] investigates active protection of the steel embedded in concrete cylinders which is treated with surface bonded carbon FRP.

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However, information provided above indicates that FRP sheets can be used both as passive protection and active protection measures. Also, a number of techniques are available to monitor rebar corrosion. However, electrochemical techniques are most suitable and efficient in monitoring corrosion of rebars.

II. EXPERIMENTAL PROGRAMME

The basic materials used in the preparation of specimens are:

Cement

Portland Pozzolana cement (PPC) is used for the present investigation. The cement is of uniform colour i.e. grey with a light greenish shade and is free from any hard lumps.

Fine Aggregates

The fine aggregates used for the experimental work is locally procured and conformed to grading zone III. Sieve Analysis of the fine aggregate is carried out in the laboratory. The sand is first sieved through 4.75mm sieve to remove any particle greater than 4.75 mm sieve and then washed to remove the dust.

Coarse Aggregate

Crushed stone aggregate of size 20 mm and 10mm are used as coarse aggregate throughout the experimental study. The aggregates are washed to remove dust and dirt and are dried to surface dry condition. The aggregates are tested as per IS: 383-1970.

Water

Fresh and clean tap water is used for casting the specimens in the present study. The water is relatively free from organic matter, silt, oil, sugar, chloride and acidic material as per Indian standard.

Pre-stressing Tendons

A standard size of tendons of length 600 mm length and 12.7 mm nominal diameter were used. The tendons are cleaned with sand paper using hexane reagent solution and then finally cleaned with petrol to remove unwanted particles from the surface of tendons.

CFRP Materials

CFRP wraps used for the study are commercially available world over. Carbon FRP sheets has been used in present investigation. The CFRP sheets are obtained from BASF construction chemicals and building systems.

Adhesive

The adhesive used for bonding FRP sheets with concrete is a Zerokor 21 AD. It is black pigmented conductive epoxy resin for saturation of MBrace fibre sheet to form in-situ FRP Composite. It is made by mixing base saturant and hardener in ratio 100:40 for 5 min. No need of adding Graphite Powder in it.

A. Design of Concrete Mix

M30 concrete mix is prepared using Portland pozzolana cement (PPC), fine aggregate and crushed stone coarse aggregate of size 20 mm and 10 mm. The mix is designed as per Indian Standard Guidelines. The ratio of cement: sand: coarse aggregate is 1:2.36:3.72. The water-cement ratio is 0.43 and compressive strength of concrete after 28 days is 36 MPa.

B. Preparation and Pre-conditioning of Pre-stressing Strands

Pre-stressing Strands of nominal size 12.7 mm diameter is used in present work. Firstly strands are cut to required length of 600. Each strands is then wire brushed to remove any surface scale .Then they are thoroughly cleaned using Hexane reagent solution and Petrol so as to remove unwanted impurities from the surface of Strands and allowed to air dry. This strand specimen preparation is similar as specified in [4].

C. Preparation of Block Specimen

The slabs are cast in mould of size (300 x 300 x 60) mm with prestressing tendons placed concentrically. When the tendons have been placed in position, concrete mix is poured and vibrations are given so that the mix gets compacted. The vibration is done until the mould is completely filled and there is no gap left. The slabs are then removed from the mould after 24 hours. After demoulding the slabs are cured for 28 days using jute bags. The concrete surface of the slabs is then cleaned and all dirt and loose materials are removed before initiation of corrosion.

D. Impressed Current Technique for Inducing Corrosion

By continuously dripping with 5% NaCl solution specimens are kept fully saturated (Fig. 1). The strand is used as anode. A stainless steel (SS) mesh is rolled around 300 mm length of specimen and tied together with metal ties in order to assure electrical continuity is used as cathode. The constant voltage of 5 mV is impressed in order to accelerate corrosion

Fig. 1 Block Specimen subjected to 5% NaCl Solution

III. CORROSION MONITORING TECHNIQUES

A. Half cell Measurement

In the present study, all the specimens are monitored daily by half-cell potential using a saturated calomel reference electrode by placing the electrode on top surface of the concrete (Fig. 4). The procedure followed is ASTM Standard C 876.

B. Linear Polarization Resistance (LPR) Measurement

Electrochemical LPR technique is especially good at measuring the localized corrosion. LPR measurement is done by using guard ring that is supplied with the field machine for precise location of strands. The Guard Ring simply connects to the front panel via the supplied cables. Incorporated into the Guard Ring is a Cu/CuSO4 reference electrode. The electrical connections are made to the pre-stressing strands.
For calculation of the corrosion current density I_{corr},
Stern-Geary equation is used; (*Song and Saraswathy 2007*)

$$I_{corr} = \frac{B}{Rp}$$

Where, B is the Stern-Geary constant and is given by B = (βa ×βc) /2.3(βa +βc). βa and βc are anodic and cathodic Tafel constants respectively.
The value of B is taken as 26mV considering steel in active condition.
Rp is the polarization resistance.

IV. WRAPPING OF PRE-CORRODED SPECIMENS

A. Method of Applying Wraps

The samples are air dried prior to the application of FRP wraps and grinder is used for rounding off the sharp corners . Manufacturer’s specifications are followed in the application of the wraps. A Wire Brush is used for roughing of slab surface so as to have proper bond between slab surface and epoxy. Conductive Epoxy in the ratio of 100:40 is used for wrapping the carbon fibre sheets onto concrete (Fig. 2 and Fig. 3).

Fig. 2 Wrapping of FRP sheet after coating Epoxy paint

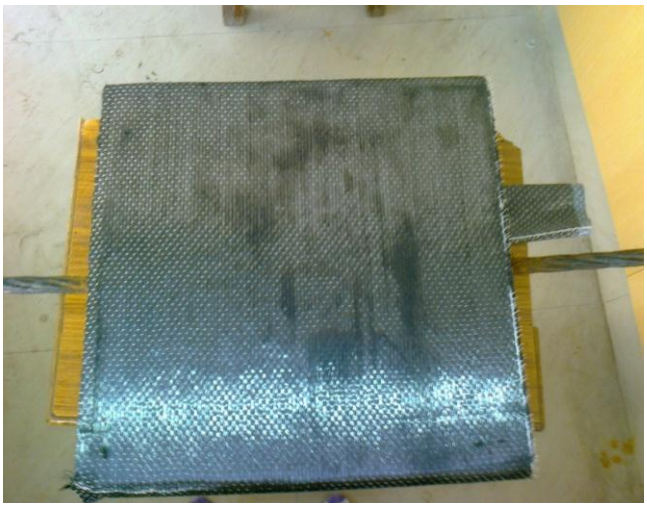

Fig. 3 FRP wrapped on concrete surface

V. CORROSION OF WRAPPED SPECIMENS

To simulate corrosion damaged structures, prior to the application of wrap, an initial exposure is applied whose time of exposure was so adjusted so as to have three levels of damage viz. onset of corrosion, onset of visible crack, and 2 days after onset of visible crack are applied. After corrosion the specimens are wrapped with FRP sheets and a constant anodic current of 10 mA is supplied with CFRP sheet as anode and tendon as cathode. Specimens for Active Protection in which positive terminal are connected to the carbon fibre ribbon and the negative terminal is connected to the pre-stressing strand (Fig. 4)**.** Corrosion monitoring is done as explained earlier using half cell potential and LPR measurements for a period of 30 days.

Fig. 4 Set up of slab specimens for Active Protection

VI. RESULTS AND DISCUSSION

Electrochemical Measurements

A. Half Cell Potential Measurements and LPR Measurements

Half-cell potential (E_{corr}) of pre-stressing tendons in all the nine slabs is recorded everyday throughout the duration of experiment. Saturated calomel electrode is used as reference electrode. Fig. 5 shows the variation of half cell potential and corrosion current density (I_{corr}) during onset of corrosion respectively during test period for one (due to less space) out of six block specimen subjected to active protection.

VII. CONCLUSIONS

1. CFRP can be used effectively in providing active protection to reinforced concrete structural components by using carbon wrap itself as anode and the tendon as cathode.
2. It is observed that active protection reduces the rate of corrosion in concrete block specimens exposed to an aggressive chloride environment to a greater extent.
3. LPR method is more reliable technique used for monitoring as compared to Half cell method.

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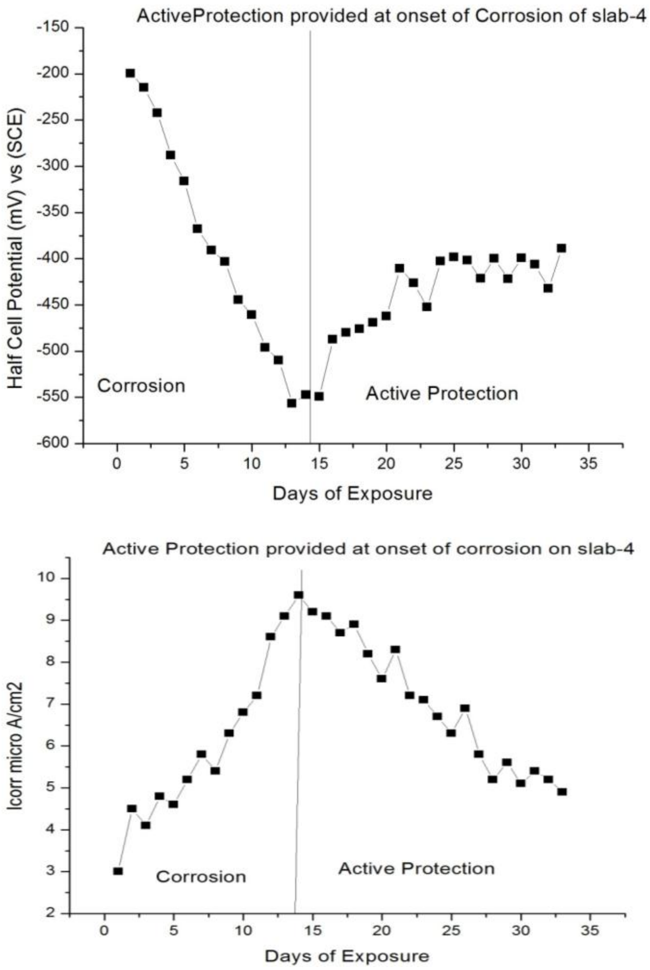

Fig. 5 Corrosion and Active Protection provided on block specimen at onset of Corrosion by Half Cell Measurement and LPR Method respectively

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