Cathodic Protection Using CFRP Sheets: A Review

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***Abstract*— Durability is the utmost importance to be taken care in case of reinforced concrete which is the most widely used construction materials in civil engineering. Corrosion of strands / tendons of steel in the concrete is one of the major problems facing today by many peoples around the world. Cathodic Protection is one of the major techniques used worldwide for rectifying the problem of corrosion by making material a cathode by impressing a DC current.**

The present paper describes and compares about the protection of the tendons achieved by using CFRP.

Specimens were allowed to be exposed to highly corrosive environment for specified time. It was also observed that the effective technique is active protection techniquefor retarding the corrosion of the tendons.

***Index Terms*— Active Protection, CFRP, Prestressing Tendons**

I. Introduction

Reinforced concrete (RC) is the most widely used material of the twentieth century which combines both concrete compressive strength and the steel tensile strength which has also proven to be successful for structural performance and durability.Corrosion is the most destructive material because of its reaction with environment which in turn leads to reduction in strength and reliability of structures. Corrosion once started leads to complete deformation of structures and finally leads to crack if not taken care.

Review of present research work shows that small amount of work hasbeen carried out in the area of active protection of tendon by CFRP sheets. [1] investigated active protection of the steel embedded in concrete treated with CFRP, [2] investigated the behavior and reduces the strengthening efficiency of using CFRP sheets, and integrated CFRP composite anchors are added to the strengthening system to delay debonding, [3] investigated the correlation and sensitivity analyses, performed to analytically characterize the load-carrying capacities of the strengthened beams with variable embedment angles and the degree of local debonding [4] 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, [5] investigatesactive protection of the steel embedded in concrete cylinders which is treated with surface bonded carbon FRP. However, information provided are very less and indicate that the FRP sheets can be used both in terms of passive protection and active protection. Also, to monitor the corrosion of tendons a number of techniques are available and are most suitable and efficient inmonitoring corrosion.

I. EXPERIMENTAL PROGRAMME

The basic materials used in the preparation of specimens are:

Cement

Portland Pozzolana cement (PPC) is used in the present investigation. The cement is of uniform grey color along with light greenish shade, which is free from any hard lumps.

Fine Aggregates

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

Coarse Aggregate

In the present research work, Crushed stone aggregate of sizes 20 mm and 10mm are used as coarse aggregate. 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 and the water is 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 in the present work. The tendons are allowed to be cleaned with sand paper using hexane reagent solution and then later cleaned with petrol in order to remove unwanted particles from the surface of tendons.

CFRP Materials

CFRP wraps used for the study are commercially available world wide. 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 [10].

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 [10]

II. 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 [10].

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 $Cu/CuSO_4$ 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 [10].

III. WRAPPING OF PRE-CORRODED SPECIMENS

A. Method of Applying Wraps

Firstly, the samples are air dried prior to the application of FRP wraps and grinder is used for rounding off the sharp corners. Manufacturer specifications are followed in the applicationof 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 [10].

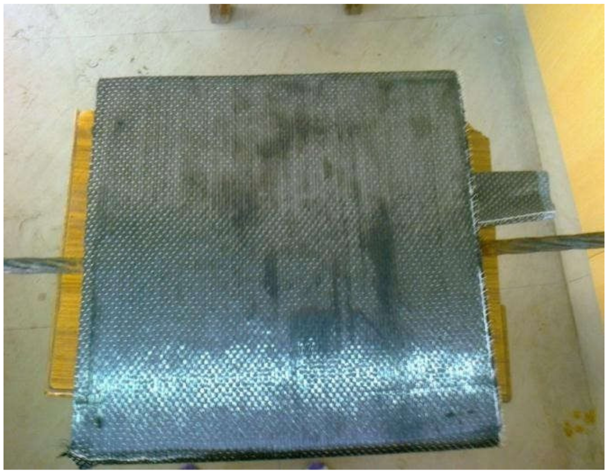

Fig. 3 FRP wrapped on concrete surface [10]

IV. 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 namely (i) onset of corrosion, (ii) onset of visible crack, and (iii) 2 days after onset of visible crack are applied. After initiation of corrosion the specimens are allowed to be wrapped with FRP sheets and also 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 fiber 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 [10].

Fig. 4 Set up of slab specimens for Active Protection [10]

V. 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 whereas Al-Sammari [2] presents a new approach that is based on both finite element simulations and previous experimental tests to quantify the additional strength attained due to the use of CFRP anchors. The quantified strength is based on examining several parameters of the anchorage system, including the number of anchors used in the sheet; the distance between anchors, anchor shaft diameter, anchor fan diameter; and CFRP sheet thickness.

VI. CONCLUSIONS

1. CFRP sheets proves to be effective in providing active protection to reinforced concrete structural components with the help of carbon wrap as anode and the tendon as cathode [10].
2. It can also be observed that the rate of corrosion in concrete block specimens can be reduced by active protection which are exposed to an aggressive chloride environment to a greater extent [10].
3. LPR method is the most reliable technique which is used for monitoring in comparison to Half-cell method [10]

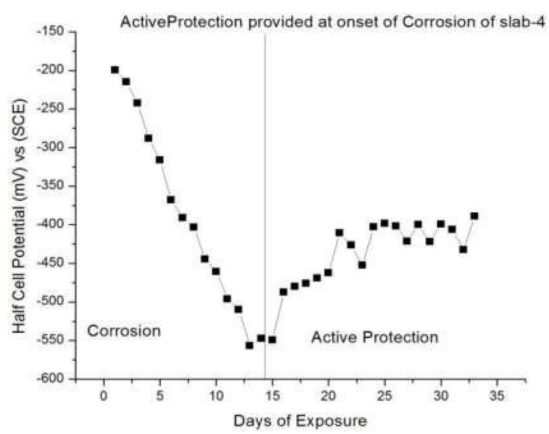

Fig. 5 Corrosion and Active Protection provided on block[10]

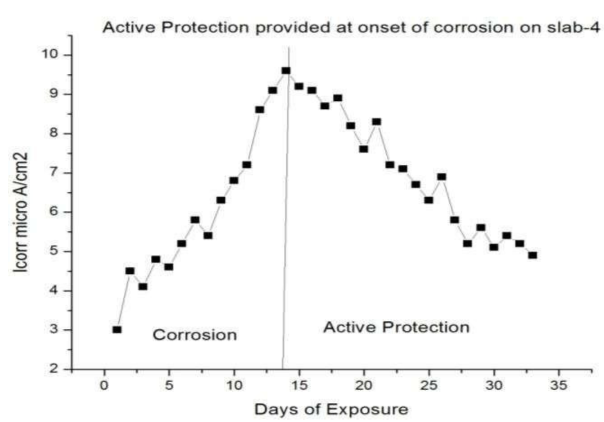

Fig. 6. specimen at onset of Corrosion by Half Cell Measurement andLPR Method respectively [10]

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