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Study on the Effectiveness of FRP Wraps in Arresting Corrosion of Reinforced Concrete Structures (Review Paper)

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ABSTRACT
Reinforced concrete is an extremely popular construction material and its major drawback is its susceptibility to environmental attack which can reduce the strength and life of the structures. This leads to development of many advanced construction materials like Fibre Reinforced Polymers (FRP). Nowadays, we developed composite members in which a prefabricated FRP casing is used initially as the form to cast plain concrete and thereafter to confine the concrete, act as tensile reinforcement and provide corrosion protection. Significant cost savings are possible with the proposed combination of materials, especially with exposed structures such as bridges. The lightweight, high strength and corrosion resistance of fiber reinforced polymers (FRP) make them ideally suited for quick and effective structural repairs. The reviewed applications of fiber reinforced polymer composites are for designing impact and blast resistant protective panels, strengthening of unreinforced masonry (URM) walls, strengthening of RC beams, and enhancing corrosion durability of RC beams. In this paper, we explain the properties of FRP's, advantages, limitations, details of experimental program relating to corrosion testing and post repair performance, test results and discussions which are observed and studied from other research works.
Keywords: Reinforced concrete (RC); Fiber reinforced polymers (FRP); Corrosion protection; Accelerated corrosion; Carbon Fibers; Glass Fibers

1. INTRODUCTION

Corrosion is the term used to describe the deterioration of a material as it reacts with its environment and is a natural process that occurs when materials such as refined metals return to a more stable compound. During the process of corrosion, an engineered material actually disintegrates into its constituent atoms as a result of chemical reactions with its surrounding environment. Corrosion can be concentrated locally to form a pit or crack or it can extend across a wide area, almost uniformly corroding the surface. Corrosion-related damage is costing developed and developing nations trillions of dollars annually in repair and replacement costs. This cost not only relates to infrastructure but also to private industrial companies that spend billions of dollars annually repairing many processing system components. A recent estimate of the worldwide direct cost of corrosion for prevention as well as repair and replacement exceeded $1.8 trillion.

One of the great advances of the Twentieth century in Materials Technology was the advent of unsaturated polyester and vinyl ester resins and their use in engineered composites. These versatile polymer materials immediately found acceptance in aerospace, construction, transportation, infrastructure and industrial process equipment, where their unique properties brought value and new solutions to the practicing engineer. FRP material consists of a mix of glass fiber reinforcements and a polymer system. The combination equals an engineered material system resulting in unique attributes replacing traditional materials such as stainless or coated steel, wood and alloys. An estimated 25 to 30 percent of the annual cost of corrosion-related damage can now be avoided if optimum corrosion management practices are employed.

One such practice includes using FRP material in corrosive environments where traditional materials do not perform as well. There are many ways to fight corrosion including using costly metals and coatings, surface treatment, and other special procedures to protect materials. In many situations, a better solution can be achieved by using modern FRP materials. Applications made using FRP are safe and reliable solutions able to face harsh conditions in many different corrosive environments and outperform traditional materials. With more than 50 years of field experience, FRP is now a proven material technology.

Understanding the properties of FRP and the environments in which it is best used will help end- users and engineers lower corrosion costs and improve performance when compared to using traditional materials. Glass fiber and resin selection is as important in using FRP material as it is when choosing a metal to fit a chemical environment.

Because of its superb corrosion resistant properties, composite fiber reinforced plastic (FRP) has displaced other more costly metals in many industrial process equipment, e.g. tanks, piping, duct and hood systems, reaction vessels, etc.

Strengthening of RC columns by wrapping with Fiber Reinforced Polymer (FRP) composite materials has been widely studied over the past decade and the performance has been verified through many laboratory tests and field applications (Debaiky et al,
2002; Harajli and Rteil 2004).

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2. PROPERTIES OF FRP

A Fiber Reinforced Polymer (FRP) composite is defined as a polymer (plastic) matrix, either thermo set or thermoplastic, that is reinforced (combined) with a fibre or other reinforcing material with a sufficient aspect ratio (length to thickness) to provide a discernible reinforcing function in one or more directions. FRP composites are different from traditional construction materials such as steel or aluminum. FRP composites are anisotropic (properties apparent in the direction of the applied load) whereas steel or aluminum is isotropic (uniform properties in all directions, independent of applied load). Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement. FRP composites are composed of:

i). Epoxy - The primary functions of the resin are to transfer stress between the reinforcing fibers, act as a glue to hold the fibers together, and protect the fibers from mechanical and environmental damage. The most common resins used in the production of FRP grating are polyesters.

ii) Reinforcements - The primary function of fibers or reinforcements is to carry load along the length of the fiber to provide strength and stiffness in one direction. Reinforcements can be oriented to provide tailored properties in the direction of the loads imparted on the end product. The largest volume in forcement is glass fiber.

iii). Fillers - Fillers are used to improve performance and reduce the cost of a composite by lowering compound cost of the significantly more expensive resin and imparting benefits as shrinkage control, surface smoothness and crack resistance.

iv). Additives - Additives and modifier ingredients expand the usefulness of polymers, enhance their process ability or extend product durability.

Composite materials are made by combining at least two different constituent materials with one or more materials as reinforcements, and one or more materials as the matrix. FRP composite is similar to RC, with a fiber (such as glass, carbon or aramid) as the reinforcement and a polymer (polymer resin matrix such as epoxy, polyester) as the matrix.

The fiber reinforcement carries load in pre-designed directions and the polymer matrix serves as a binder, a medium to transfer loads between adjacent fibers and to provide protection for the fiber. Current FRP composite materials typically have high strength and high-stiffness structural fibers embedded in lightweight, low-cost, and environmentally resistant polymers; which have better mechanical and durability properties than either of the constituents alone. FRP products produced for use in structural engineering can comprise significantly more ingredients than just the primary constituents: fiber and polymer resins (Shaikh Zahoor Khalid et al, 2009).

3. ADVANTAGES AND LIMITATIONS OF FRP

FRP has tremendous potential and has great advantages over conventional materials and techniques of retrofitting of RC structures. The increase in use of FRP for retrofitting of RC structures may be attributed to their advantageous properties mainly - high corrosion resistance, light weight, extremely high strength to weight ratio, ease of handling and installation (hence substantially reduced working time). The following are major pros and cons of using Composites:

i). Advantages

1) Corrosion proof.
2) Higher UTS and Young's modulus.
3) Easy in transportation and can be installed easily.
4) Light weight. Hence, very high strength to weight ratio.
5) High fatigue resistance.
6) Joints can be easily avoided as they are available in desired length.

ii). Limitations

1) Low ductility value and fickly plastic behavior
2) Susceptible to local unevenness.
3) High cost.
4) Low shear strength

FRP's can be used in the concrete structures in following forms:

1) Plates- at the face to improve the tension Capacity.
2) Laminates- below beams and slabs to improve load taking capacity.
3) Bars- as reinforcements in beams and slabs replacing the steel bars
4) Cables- can be used as tendons and post- tension members in suspension and bridge girders.
5) Wraps- around concrete members i.e. columns, beams, slabs etc for confinement (Shaikh Zahoor Khalid et al, 2009)

4. EXPERIMENTAL PROGRAM

4.1. Corrosion testing

FRP’s are unaffected by electromechanical/electrochemical deterioration and can resist aggressive corrosive effects of acids, alkalis, salts and similar aggregates under a wide range of temperatures. They provide a barrier layer that should impede further corrosion of steel. The conductive FRP wrap-around can be used as inert anodes and the reinforcement can act as cathode during impressed current cathodic protection to impede the corrosion of steel. The FRP wraps in the corrosion affected areas have not shown any sign of deterioration in six years.

The general procedure of laboratory experiments has been to accelerate corrosion in steel embedded in concrete and then applying the FRP to observe its effects on corrosion. The main indicators of performance are mass loss of reinforcement, pull out strength, electric resistance, half cell potentials and potential scans.

In this review paper, we report a part of an ongoing investigation on the efficacy of FRP wraps in providing both active and passive protection to steel reinforcements in concrete that is already damaged by corrosion. The experimental program was carried out in following steps,

1. Casting cylindrical reinforced concrete specimens.
2. Inducing corrosion into the reinforced concrete specimens and Potential dynamic electrochemical anodic polarization scans and Half-cell potential surveys are done.
3. Wrapping the pre-corroded specimens with CFRP and GFRP sheets.
4. Subjecting the wrapped specimens to further corrosion by passing anodic current.
5. Carrying out Pullout test on corroded wrapped Specimens.
6. Determining Percentage mass loss in reinforcing bar after corrosion

(Sangeeta Gadve et al, 2009)

In another study, researchers investigated the effect of various configurations of CFRP wraps and two-part epoxies on the corrosion-induced mass loss of steel rebar in reinforced concrete. One experimental technique to expedite reinforcing bar corrosion in concrete samples uses exposure to aggressive conditions while forcing corrosion activity through galvanostatic corrosion. In this technique, direct current is impressed into the steel reinforcement so that it becomes the anode while an auxiliary element serves as a cathode. When a constant voltage is maintained between the anode and cathode, the current level is proportional to the speed of the corrosion process (Lisa K.Spainhour and Isaac A.Wootton, 2008).

4.2. POST REPAIR PERFORMANCE

In another study, the concept of external confinement as the strengthening element of corrosion- damaged columns was explored not only as a remedy for strength recovery, but also as a means of delaying or even arresting the process of corrosion by proper design of the confining system. Performance variables used to gauge the efficacy of each repair scheme were (1) the rate of post repair corrosion after repeat conditioning of the repaired specimens to corrosive environments; and (2) mechanical properties (i.e., strength, ductility and volumetric expansion) of the repaired specimens under uniaxial compression.

Two types of cylindrical specimens are considered. (S series and H series with no transverse reinforcement) The basic elements of the repair methods tested in this experimental study were

1. A layer of dense low-permeability grout overlaid on the damaged concrete.
2. A diffusion barrier to minimize penetration of moisture and oxygen, and reverse leaching of alkalis from the grout.
3. Fiber composites wrapped around the repaired specimens, to induce passive confining stresses in response to future expansion of the encased concrete.
4. After repairs, Accelerated corrosion test takes place.
5. Electrical current and radial expansion strains were continuously monitored to assess the influence of the various repair methods on the resulting corrosion rate.

(Bonacci et al, 2001)

5. RESULTS AND DISCUSSIONS

1. The initial observed potentials indicated that the steel was in passive condition that is virtually no corrosion was occurring.
2. The bare sample had the highest I_{corr}. In comparison all the wrapped samples had a significantly lower I_{corr}. Lower I_{corr} for all the wrapped samples establishes that wrapping significantly reduces the rate of corrosion.
3. The glass wrapped specimens exhibited lower I_{corr} than the carbon wrapped specimens. This seems

to be due to the higher electrical resistance offered by the GFRP than the CFRP.

4. A linear fit of the data shows that pullout strength is inversely proportional to the mass loss.
5. A careful study of the wrapped samples reveals that prior to the wrapping the cell voltages in samples were very similar to that of the control samples. However, right after the wrapping all samples exhibited dramatically higher cell voltage. This indicates that the resistance to corrosion increases enormously with wrapping. Immediately after wrapping the cell voltages went up with time. This implies that the corrosion products formed remained entrapped into the cracks and thus fill them with non conducting corrosion products, due to their confinement of the concrete, thereby increasing the electrical resistivity of the system.
6. In another study, the cumulative theoretical mass loss values based on Faraday's law correlate well to actual recorded mass loss values, regardless of sample style. This indicates that neither the wraps (number of layers and layer orientation) nor the epoxy (type and thickness) has a significant effect on the validity of the theoretical predictions. In addition, because of the strong correlation, the theoretical mass loss values can be used to examine the corrosion behavior of the samples over time.
7. A comparison of the predicted mass loss versus time graphs clearly reveals that the CFRP wraps are able to delay to onset of corrosion, lengthen sample test lives, and lower overall rates of corrosion mass loss.
8. It is interesting to note that the options with a diffusion barrier demonstrated higher loss of steel section, indicating their resistivity was lower than that of the other repaired specimens. It appears that moisture entrapped during casting of the external grout layer could not easily dry because both the GFRP jacket and the diffusion barrier sealed the specimen, thus eliminating the main route for convective activity. (Bonacci et al, 2001)

6. CONCLUSIONS

1. Wrapping dramatically slows down the rate of corrosion. One should expect increase in pullout strength, decrease in mass loss and increase in corrosion current (I_{corr}) due to wrapping.
2. Glass seemed to have impeded the corrosion more than the carbon fibers. This may be due to higher electrical resistance of the glass fiber.
3. The choice of sheets in field application depends on several other factors such as the required stiffness, strength, durability, creep resistance and fatigue resistance. Therefore, the choice of fiber may be made based on all those factors along with their relative resistance to corrosion
4. .CFRP wrapping is effective at abating reinforcement corrosion by delaying the onset of corrosion, lengthening sample test lives and reducing the rate of corrosion mass loss.
5. Epoxy type is a significant factor affecting the performance and corrosion resistance of a CFRP wrap. One type of epoxy used for the CFRP wraps in this experiment (Sikagard 62 - SG) is considerably more effective at delaying the onset and reducing the rates of corrosion in samples than another (West System 105-WS).
6. The motivating premise of all the repair options considered was that external confinement in the form of jacketing could alter favorably the process of corrosion by slowing down the rate of the corrosion reaction, and imparting ductility and strength to the affected structural element. FRP wraps, being strong and corrosion-resistant, proved very effective as jacketing material.
7. Performance was markedly improved when increasing the number of FRP layers used in the jacket.
8. The repair option that performed best with regard to the post repair corrosion rate,

Strength recovery, and deformation capacity was also the simplest and easiest to implement alternative, consisting of cleaning the damaged surface (but without removal of contaminated or cracked cover concrete) and wrapping directly on layers of fiber-reinforced composite wraps.

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