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Review on Corrosion Inhibition of Concrete using FRP Mats

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Abstract

Equally the scope of applications for fiber-reinforced polymer (FRP) sheets in civil engineering constantly increases, there is a lot of concern with relevance their performance in essential environments the fireplace behavior of composite materials is very necessary since advanced physical and chemical processes like the glass transition and decomposition occur once these materials area unit subjected to elevated and high temperatures, probably resulting in extensive loss of stiffness and strength. This article shows a study on FRP sheets as a corrosion inhibition of concrete.
Keywords: FRP, Concrete, Corrosion

I. Introduction

The strengthening or retrofitting of existing concrete structures to resist higher design loads, correct strength loss due to deterioration, correct design or construction deficiencies, or increase ductility has traditionally been accomplished using conventional materials and construction techniques. Externally bonded steel plates, steel or concrete jackets and external post-tensioning are just some of the many traditional techniques available. Composite materials made of fibers in a polymeric resin, also known as fiber-reinforced polymers (FRPs), have emerged as an alternative to traditional materials for repair and rehabilitation. For the intents of this document, an FRP system is determined as the fibers and resins used to create the composite laminate, all applicable resins used to stick it to the concrete substrate, and all applied coatings used to protect the component materials. Coatings used exclusively for aesthetic reasons are not considered part of an FRP system. FRP materials are lightweight, noncorrosive, and exhibit high tensile force. These fabrics are readily usable in various varieties, ranging from factory-made laminates to dry fiber sheets that can be wrapped to conform to the geometry of a structure before adding the polymer resin. The relatively thin profiles of cured FRP systems are often desirable in applications where aesthetics or access is a vexation. The rising interest in FRP systems for strengthening and retrofitting can be assigned to many genes. Although the fibers and resins used in FRP systems are relatively expensive compared with traditional strengthening materials such as concrete and steel, labor and equipment costs to install FRP systems are much more depressed. FRP systems can likewise be applied in areas with limited access where traditional techniques would be difficult to enforce.

II. Scope and limitations

The durability and long-term performance of FRP materials has been the topic of much research; nevertheless, this research remains ongoing. Care is advised in applications where the FRP system is submitted simultaneously to extreme environmental and stress conditions. The factors associated with the long-term durability of the FRP system may as well touch on the tensile modulus of elasticity of the cloth utilized for conception. Many issues regarding bond of the FRP system to the substrate remain the focal point of a great pile of research. For both flexural and shear strengthening, there are many different varieties of debonding failure that can regulate the effectiveness of an FRP-strengthened member. While most of the depending modes have been keyed out by researchers, more accurate methods of predicting debonding are still required. Throughout the design processes, significant limitations on the strain level achieved in the FRP material (and thusly, the stress level reached) are imposed to conservatively account for debonding failure modes. Future development of these design processes should include more thorough methods of predicting debonding

A. Strengthening Limits

In general, to prevent sudden failure of the member in case the FRP system is damaged, strengthening limits are imposed such that the increment in the freight-bearing capacity of a member strengthened with an FRP system be fixed. The philosophy is that a loss of FRP reinforcement should not cause member failure under sustained service load.

FRP systems used to increase the effectiveness of an existing member should be projected in accordance with a comprehensive treatment of load limitations, rational load paths, effects of temperature and environment on FRP systems, loading considerations, and effects of reinforcing steel corrosion on FRP system integrity.

B. Fire and Safety Improvements

FRP-strengthened structures should comply with all applicable building and fire codes. Smoke generation and flame spread ratings should be satisfied for the gathering according to applicable building codes depending on the categorization of the edifice. Smoke and flame spread ratings should be settled in conformity with ASTM E84. Because of the degradation of most FRP materials at high temperature, the strength of externally bonded FRP systems is assumed to be lost completely in a fire, unless it can be shown that the FRP temperature remains under its critical temperature (for example, FRP with a flame-protection scheme). The critical temperature of an FRP strengthening system should be considered as the lowest glass-transition temperature tug-of the components of the repair system. The structural member without the FRP system should have sufficient strength to resist all applicable service loads during a blast. The fire endurance of FRP-strengthened concrete members may be ameliorated through the usage of certain resins, coatings, insulation systems, or other methods of flame protection.

C. Maximum Service Temperature

The physical and mechanical attributes of the resin components of FRP systems are determined by temperature and degrade at temperatures close to and above their glass-transition temperature Tg. The Tg for FRP systems typically ranges from 140 to 180 °F (60 to 82 °C) for existing, commercially available FRP systems. The tg for a particular FRP system can be got from the system manufacturer.

III. PHYSICAL PROPERTIES

A. Density

FRP materials have densities ranging from 75 to 130 lb/ft3 (1.2 to 2.1 g/cm3), which is four to six times more depressed than that of steel. The reduced density leads to lower shipping costs, reduces added dead load on the structure, and can facilitate handling of the materials on the project website.

B. Effects of High Temperatures

Beyond the tag, the elastic modulus of a polymer is significantly shortened due to alterations in its molecular construction. The value of the tg depends on the case of resin, but is usually in the area of 140 to 180 °F (60 to 82 °C). In an FRP composite material, the fibers, which exhibit better thermal properties than the resin, can extend to support some load in the longitudinal direction until the temperature threshold of the fibers is achieved. This can happen at temperatures exceeding 1800 °F (1000 °C) for carbon fibers, and 350 °F (175 °C) for aramid fibers. Glass fibers are capable of withstanding temperatures in excess of 530 °F (275 °C). Due to a reduction in force transfer between fibers through bond to the resin, however, the tensile properties of the overall composite are reduced. Test results indicate that temperatures of 480 °F (250 °C), a good deal higher than the resin Tg, will reduce the tensile strength of GFRP and CFRP materials in excess of 20% (Kumahara et al. 1993). Other properties affected by the shear transfer through the resin, such as bending strength, are brought down significantly at lower temperatures (Wang and Evans 1995). For bind-critical applications of FRP systems, the properties of the polymer at the fiber-concrete interface are essential in keeping the bond between FRP and concrete. At a temperature close to its tag, however, the mechanical properties of the polymer are significantly trimmed back, and the polymer starts to miss its power to shift stresses from the concrete to the fibers.

IV. MECHANICAL PROPERTIES

A. Tensile Behavior

When loaded in direct tension, unidirectional FRP materials do not exhibit any plastic behavior (yielding) before rupture. The tensile behavior of FRP materials consisting of one type of fiber material is qualified by a linear elastic stress-strain relationship until failure, which is sudden and brittle. The tensile strength and rigor of an FRP material is dependent on various components. Because the characters in an FRP material are the primary load-carrying constituents, the type of character, the orientation of fibers, the quantity of fibers, and method and conditions in which the composite is produced affect the tensile properties of the FRP material. Referable to the primary part of the fibers and methods of application, the properties of an FRP repair system are sometimes reported based on the net-fiber area. In other cases, such as in precured laminates, the reported properties are grounded on the gross-laminate area. The gross-laminate, area of an FRP system is estimated utilizing the total cross-sectional area of the cured FRP system, letting in all fibers and resin. The gross-laminate, area is typically utilized for reporting precured laminate properties where the cured thickness is constant and the relative balance of fiber and resin is contained.

The net-fiber area of an FRP system is estimated utilizing the known area of fiber, neglecting the total width and heaviness of the cured system; thus, resin is excluded. The net-fiber area is typically utilized for describing properties of wet lay-up systems that use manufactured fiber sheets and field installed resins. The wet layup installation process leads to controlled fiber content and variable resin content. System properties reported using the cross-laminate, area has higher relative thickness dimensions and lower relative strength and modulus values, whereas system properties reported using the net-fiber area have lower relative thickness dimensions and higher relative strength and modulus values. Irrespective of the basis for the reported values, the load carrying strength and axial stiffness of the compost remains constant. Properties reported based on the net-fiber area are not the properties of the bare fibers. When examined as a component of a cured composite, the measured tensile strength and ultimate rupture strain of the net-fiber are typically lower than those measured based on a dry fiber test. The attributes of an FRP system should be characterized as a composite, recognizing not just the material properties of the individual characters, but also the efficiency of the fiber resin system, the fabric architecture, and the method used to make the composite. The mechanical properties of all FRP systems, regardless of course, should be based on the testing of laminate samples with known fiber content. The tensile properties of a particular FRP system, nevertheless, can be obtained from the FRP system manufacturer or using the test appropriate method as described in ACI 440.3R and ASTM D3039 and D7205. Young's modulus should be counted as the chord modulus between 0.003 and 0.006 strains, in accordance with ASTM D3039. A minimum number of 20 replicate test specimens should be applied to define the ultimate tensile properties. The manufacturer should supply a description of the method applied to obtain the reported tensile properties, including the number of tests, mean values, and standard deviations.

B. Compressive behavior

Externally bonded FRP systems should not be used as compression reinforcement due to insufficient testing validating its use in this type of application. While it is not urged to rely on externally bonded FRP systems to resist compressive stresses, the following part is demonstrated to fully characterize the behavior of FRP materials. Coupon tests on FRP laminates used for repair on concrete have shown that the compressive strength of FRP is lower than the tensile strength (Wu 1990). The mood of failure for FRP laminates subjected to longitudinal compression can include transverse tensile failure, fiber micro buckling, or shear failure. The modal value of failure depends on the type of fiber, the fiber-volume fraction, and the type of rosin. Compressive strengths of 55, 78, and 20% of the tensile strength have been reported for GFRP, CFRP, and AFRP, respectively (Wu 1990). In general, compressive forces are higher for materials with higher tensile strengths, except in the case of AFRP, where the fibers exhibit nonlinear behavior in compression at a comparatively low degree of strain.

V. RESEARCH BACKGROUND

The University of Toronto conducted an experiment using seven third-scale examples of reinforced concrete pillars that had cast-in-place chlorides around the reinforcement as well as a high water-to-cement ratio. Five of these towers were then subjected to accelerated erosion by an impressed current through the reinforcement for 49 workweeks. Next, three of the corroded columns were restored with a carbon fiber wrap. It was found that the carbon wrap improved the ductility and durability of the corroded members. Specifically the carbon wrap increased the cargo bearing capacity of the column 28 percent and cut down the corrosion rate by 50 percentage. Interestingly, the corrosion damaged and wrapped column that achieved the increase of 28 percent due to the wrap actually exceeded the load capability of the control tower. Besides the increased ductility of a wrapped column was established when its axial deformation was greater than six times that of the control specimen during the ultimate load test.

Tang et. al. conducted experiments that utilized glass wraps in both a sphere and a research lab setting in Indiana. Three layers of FRP wrap along with two layers of a protective coat were used on reinforced concrete pillars. Nevertheless, two of the wrapped columns were damaged in an automobile incident and it was observed that at one time the epoxy cover was removed, the glass fibers became exposed to wet and swelled. This growth in volume caused additional harm to other characters. In the laboratory, over 80 specimens were constructed and wrapped with varying layers of FRP or just the epoxy resin. These were then subjected to an accelerated corrosive environment where they were cycled through one week in a five percent salt solution and then allowed one week to air dry. This continued for 40 weeks. The final ending of this experiment was that the glass FRP or just the epoxy resin by itself provides an excellent security system against corrosive agents.

Scarth and Keble, in England, have conducted research on glass FRP's ability to inhibit corrosion and chloride penetration. They selected six reinforced concrete column sites that exhibited signs of chloride contamination. It was found that higher levels of chloride were in the bottom third of the column and in joints where water leaked. Due to concern that the corrosion may continue once the wraps were in office and there would be no means to visibly inspect the concrete, a permanent corrosion monitoring system (PCMS) was established. Once this scheme was in place, glass FRP wrap was applied to the entire tower with three layers in the bottom third region and decreasing layer amounts higher up the tower. In the final two years, the data from the PCMS has not altered, which has led to Scarth and Keble's "conclusion that the glass FRP provides an impermeable barrier to chlorides".

Nevertheless, the Florida's DOT conducted tests that did not turn out to be equally successful as those previously cited. The Florida DOT wrapped only the mid-splash zone of reinforced concrete columns located in a marine environment with a fiberglass cap. They establish that through capillary action the water climbed up in the column behind the wrap and became trapped along with the chlorides it transported which ultimately increased the erosion rate. The wrap effectively keeps any visual inspections from observing the corrosion behind it which gets this post yet more perilous. New York's DOT launched a similar plan in 1998 that looked into the effectiveness of FRP for preserving deteriorated concrete. Six pillars that had extensive deterioration were wrapped on the Court Street Bridge in Owego, New York with both carbon and glass fibers. After five years of exposure to the surroundings, the wraps will be transferred along with the columns for testing to see how effective the wraps are as a rehabilitative mechanism.

Subhash C Goel et. al. In their article Experimental Study On The Performance Of The RC Research On New Materials, Elements And Systems concluded that research work carried out in both states in developing and application of novel and innovative materials for use in advanced composite structural elements and systems (Research For Innovation - RFI) under the US-Japan Cooperative Earthquake Research Program on Composite and Hybrid Structures. Therefore, the subjects in this group are more of feasibility type than those in the other three groups, Concrete filled tube composite system, RC column – steel beam composite system and RC core wall – steel frame composite system, where the objectives are to develop detailed guidelines for practical design work. The research work includes Fiber Reinforced Plastics (FRP), and High Performance Concretes (HPC). Use of FRP materials has been studied in RC-FRP panels, fixing and toning up of existing RC members by FRP, and use of FRP in electrical installations. Light weight concretes with specific gravity of 1.2 to 1.6 and compressive strength of 30 to 60 MPa, and advanced cementations composites with ultra ductile behavior are under development. A few innovative composite systems consisting of steel and fiber reinforced concrete (FRC) have also been considered. In these schemes, the structural elements are made of selective combinations of FRC and steel members. The combinations under study include: FRC-encased open web steel joists, and high performance FRC core encased in slurry infiltrated mat concrete (SIMCON) shells for reinforcement as well as stick-in-place form work. Studies on selective use of High Performance Fiber Reinforced Cementations Composites (HPFRCC) in critical elements and regions of composite constructions, such as joints and connections of precast elements, have produced first-class outcomes.

C. E. Bakis et. al. In article Fiber-Reinforced Polymer Composites for Construction—State-of-the-Art Review states that A concise state-of-the-art survey of fiber-reinforced polymer ~also known as fiber-reinforced plastic! Composites for construction applications in civil engineering is awarded. The report is formed into separate sections on structural shapes, bridge decks, internal reinforcements, externally bonded reinforcements, and standards and codes. Each segment includes a historical review, the current state of the art, and future challenges. This paper attests to the many potential applications of FRP composite materials in construction, although the demand for brevity prevents all topics from being fully addressed. It can be stated that the amount of experience with diverse kinds of FRP construction materials varies in conformity with the perceived near-term economic and safety benefits of the cloths. In the example of externally bonded reinforcements, for example, the immediate cost and safety benefits are clear, and adoption of the material by industry is widespread. In other cases where FRP materials are believed to be primary load-carrying parts of social organizations, field applications still maintain a research flavor while long-term experience with the material accumulates. A bit of careful monitoring programs of social systems with primary FRP reinforcement have been set up around the globe and should provide this experience base in the upcoming age. Standards and codes for FRP materials and their function in structure are either published or currently being written in Japan, Canada, the United States, and Europe. These official documents are typically similar in format to conventional standards and codes, which should facilitate their acceptance by governing agencies and governing bodies. The most significant mechanical differences between FRP materials and conventional metallic materials are the highest strength, lower stiffness, and linear-elastic behavior to failure of the former. Other differences such as the thermal expansion coefficient, moisture absorption, and high temperature and fire resistance need to be seen as good. The teaching and training of engineers, building workers, inspectors, and owners of social organizations along the various relevant aspects of FRP technology and drill will be important in the successful application of FRP materials in building. Nevertheless, it should be stressed that even with anticipated moderate decreases in the cost of FRP materials; their role will be primarily limited to those applications where their unique properties are crucially required.

Tamer A. El Maaddawy and Khaled A. Sudoku concluded that in their article i.e. Effectiveness of Impressed Current Technique to Simulate Corrosion of Steel Reinforcement in Concrete Accelerated corrosion by means of the impressed current technique is widely practiced in concrete strength tests. In this work, the influence of varying the impressed current density level between 100 and 500 mA/cm^2 on the actual grade of steel reinforcing bar corrosion as well every bit on the concrete strain behavior due to expansive corrosion products was experimentally investigated. Twelve reinforced-concrete prisms ~15032503300 mm! Were they used? The prisms were reinforced by two No. 10 reinforcing bars. Corrosion was induced by means of impressed current using electric power supplies. To depassify the steel reinforcement, 5% NaCl by weight of cement was added to the concrete mix. The stress response due to the expansion of corrosion products was evaluated at each aspect of the prisms. At the close of the corrosion phase, all the corroded reinforcing bars were taken away, cleaned according to the ASTM G1-90 standard, and weighed to get the actual degree of volume deprivation. The results demonstrated that, up to 7.27% mass loss, accelerated corrosion using the impressed current technique was effective in inducing corrosion of the steel reinforcement in concrete. With respect to Faraday's law, the function of different current densities has no consequence on the percentage of volume deprivation. Nevertheless, increasing the degree of current density above 200 mA/cm2 results in a substantial gain in the strain response and crack width due to erosion of the steel support.

Nabeel Shaikh, Sheetal Sahara in article Effect Of Impressed Current On The Corrosion Of Reinforcing Bar In Reinforced Concert states that Corrosion of steel reinforcing bar is one of the major reasons of premature deterioration reducing the service life of reinforced concrete (RC) structures. This increases maintenance and repair cost of the RC structures. In RC structures, corrosion of steel in natural condition is a very slow procedure. Hence, generally accelerated corrosion techniques are used in the lab to simulate the natural erosion process. An experimental study was borne out to examine the effect of impressed current on corrosion of steel reinforcing bar in concrete. In this experiment, three different voltage 4V, 6V and 10V were used and was impressed on reinforced bar in concrete. A cylindrical specimen of 100mm diameter and 200mm height reinforced with bar diameter 16mm and 20mm concentrically were used and analyzed for the impression of different voltages used. It has been noted that Mass loss decreases with increase in the C/D ratio for same voltage applied up to development of first visible surface crack on concrete specimen. Mass loss decreases with an increase in voltage for same C/D ratio up to the development of first visible surface crack on concrete specimen.

VI. CONCLUSION

In present study, the scope as well as limitations of FRP as construction material is evaluated. The FRP owing to its durability and strength is found to have a wide scope of application. However, there are various limitations which hinder its large scale use especially in developing countries like India. The strength, fire and temperature are found to have certain limitations in FRP concrete.

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