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A Review of Fiber Reinforced Polymer (FRP) on Concrete

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Abstract— Fiber reinforced polymer composites (FRPs) are increasingly being considered as an enhancement to and or substitute for infrastructure components or systems that are constructed of traditional civil engineering materials, namely concrete and steel. FRP composites are lightweight, no-corrosive, exhibit high specific strength and specific stiffness, are easily constructed, and can be tailored to satisfy performance requirements. Due to these advantageous characteristics, FRP composites have been included in new construction and rehabilitation of structures through its use as reinforcement in concrete, bridge decks, modular structures, formwork, and external reinforcement for strengthening and seismic upgrade. Fiber Reinforced polymer is a composite material which have many advantages and disadvantages on concrete structures.

Keywords: Fiber Reinforced Polymer, Composite, Advantages, Disadvantages

I. INTRODUCTION

Fiber-reinforced polymer(FRP), is a composite material which reinforced with fibers and formedby polymer matrix. The fibers are generally glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. FRPs are used in many industries like aerospace, automotive, marine, and construction industries. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde resins are largely used.

Composite materials are formed by naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and unique within the finished structure. Most composites have strong, stiff fibers in a matrix which is weaker and less stiff. FRP objective is generally to construct a component which is strong and stiff, often with a low density. Commercial material commonly has glass or carbon fibers in matrices based on thermosetting polymers, such as epoxy or polyester resins. FRP show in various properties of concrete like creep, wear, fracture toughness, thermal stability, etc. Fiber reinforced polymer (FRP) are composites used in almost every type of Morden engineering structure, with their usage is from aircraft, helicopters and spacecraft through to boats, ships and offshore platforms and to automobiles, sports goods, chemical processing equipment and civil infrastructure such as bridges and buildings. The usage of FRP composites continues to grow at an impressive rate as these materials are used more in their existing markets and become established in relatively new and Concrete structures. A key factor driving the increased applications of composites over the recent years is the development of new advanced forms of FRP materials. In this paper many positive and negative property of Fiber Reinforced Polymers (FRP) is discussed.

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 purposes of this document, an FRP system is defined as the fibers and resins used to create the composite laminate, all applicable resins used to bond it to the concrete substrate, and all applied coatings used to protect the constituent materials. Coatings used exclusively for aesthetic reasons are not considered part of an FRP system. FRP materials are lightweight, noncorrosive, and exhibit high tensile strength. These materials are readily available in several forms, 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 concern. The growing interest in FRP systems for strengthening and retrofitting can be attributed to many factors. 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 often lower. FRP systems can also be used in areas with limited access where traditional techniques would be difficult to implement.

II. SCOPE AND LIMITATIONS

The durability and long-term performance of FRP materials has been the subject of much research; however, this research remains ongoing. Caution is advised in applications where the FRP system is subjected simultaneously to extreme environmental and stress conditions. The factors associated with the long-term durability of the FRP system may also affect the tensile modulus of elasticity of the material used for design. Many issues regarding bond of the FRP system to the substrate remain the focus of a great deal of research. For both flexural and shear strengthening, there are many different varieties of debonding failure that can govern the strength of an FRP-strengthened member. While most of the debonding modes have been identified by researchers, more accurate methods of predicting debonding are still needed. Throughout the design procedures, significant limitations on the strain level achieved in the FRP material (and thus, the stress level achieved) are imposed to conservatively account for debonding failure modes. Future development of these design procedures should include more thorough methods of predicting debonding

III. 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 increase in the load-carrying capacity of a member strengthened with an FRP system be limited. The philosophy is that a loss of FRP reinforcement should not cause member failure under sustained service load. FRP systems used to increase the strength of an existing member should be designed in accordance with a comprehensive discussion 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.

IV. FIRE AND LIFE SAFETY-FRP

Strengthened structures should comply with all applicable building and fire codes. Smoke generation and flame spread ratings should be satisfied for the assembly according to applicable building codes depending on the classification of the building. Smoke and flame spread ratings should be determined in accordance 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 demonstrated that the FRP temperature remains below its critical temperature (for example, FRP with a fire-protection system). The critical temperature of an FRP strengthening system should be taken as the lowest glass-transition temperature *Tg*of the components of the repair system. The structural member without the FRP system should possess sufficient strength to resist all applicable service loads during a fire. The fire endurance of FRP-strengthened concrete members may be improved through the use of certain resins, coatings, insulation systems, or other methods of fire protection.

V. MAXIMUM SERVICE TEMPERATURE

Thephysical and mechanical properties of the resin components of FRP systems are influenced 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 obtained from the system manufacturer.

VI. 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 lower than that of steel. The reduced density leads to lower transportation costs, reduces added dead load on the structure, and can ease handling of the materials on the project site.

B. Effects of High Temperatures:

Beyond the *Tg*, the elastic modulus of a polymer is significantly reduced due to changes in its molecular structure. The value of *Tg* depends on the type of resin but is normally in the region 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 continue to support some load in the longitudinal direction until the temperature threshold of the fibers is reached. This can occur at temperatures exceeding 1800 °F (1000 °C) for carbon fibers, and 350 °F (175 °C) for aramid fibers. Glass fibers are capable of resisting 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 have indicated that temperatures of 480 °F (250 °C), much 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 reduced significantly at lower temperatures (Wang and Evans 1995). For bond-critical applications of FRP systems, the properties of the polymer at the fiber-concrete interface are essential in maintaining the bond between FRP and concrete. At a temperature close to its *Tg*, however, the mechanical properties of the polymer are significantly reduced, and the polymer begins to lose its ability to transfer stresses from the concrete to the fibers.

VII. 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 characterized by a linear elastic stress-strain relationship until failure, which is sudden and brittle. The tensile strength and stiffness of an FRP material is dependent on several factors. Because the fibers in an FRP material are the main load-carrying constituents, the type of fiber, 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. Due to the primary role 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 instances, such as in precured laminates, the reported properties are based on the gross-laminate area. The gross-laminate area of an FRP system is calculated using the total cross-sectional area of the cured FRP system, including all fibers and resin. The gross-laminate area is typically used for reporting precured laminate properties where the cured thickness is constant and the relative proportion of fiber and resin is controlled. The net-fiber area of an FRP system is calculated using the known area of fiber, neglecting the total width and thickness of the cured system; thus, resin is excluded. The net-fiber area is typically used for reporting properties of wet layup 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 gross-laminate area have 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. Regardless of the basis for the reported values, the loadcarrying strength (ffuAf) and axial stiffness (AfEf) of the composite remain constant. Properties reported based on the net-fiber area are not the properties of the bare fibers. When tested as a part 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 properties of an FRP system should be characterized as a composite, recognizing not just the material properties of the individual fibers, but also the efficiency of the fiberresin system, the fabric architecture, and the method used to create the composite. The mechanical properties of all FRP systems, regardless of form, should be based on the testing of laminate samples with known fiber content. The tensile properties of a particular FRP system, however, 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 calculated as the chord modulus between 0.003 and 0.006 strain, in accordance with ASTM D3039. A minimum number of 20 replicate test specimens should be used to determine the ultimate tensile properties. The manufacturer should provide a description of the method used 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 recommended to rely on externally bonded FRP systems to resist compressive stresses, the following section is presented 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 mode of failure for FRP laminates subjected to longitudinal compression can include transverse tensile failure, fiber micro buckling, or shear failure. The mode of failure depends on the type of fiber, the fiber-volume fraction, and the type of resin. 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 strengths are higher for materials with higher tensile strengths, except in the case of AFRP, where the fibers exhibit nonlinear behavior in compression at a relatively low level of stress.

C. Advantages:

1) Strength:

Carbon and glass fibers are strong and they possess good strengths as fiber sand slightly less than this as bundles or as pultrusions. These strengths are more than prestressing steels.

2) Stiffness:

The stiffnesses of fibers are high enough to make them useable; Stiffness is depending on grade but FRP is least stiff as we compare it to aluminum but certain cases they are as stiff as steel.

3) Durability:

We know that our fibers do not rust, at least in the same way as steel. FRP are not going to give expanding rust that bursts the cover and leads to staining on the outside the concrete. In particular, they are resistant to attack by chlorides, which are the bane of any structural engineer's life when designing near roads and sea coast.

4) Creep:

Earlier studies shows that the amount of creep is negligible for reinforced concrete and gives losses of force for prestressed concrete that is similar to that in structures with steel tendons. Creep to failure though will appear as a weakness.

5) Prevention to Corrosion:

Corrosion of steel in concrete involves certain processes, different from those in other natural environments. Some theories and techniques used in traditional corrosion field may not be directly applicable in the corrosion of reinforced concrete. The cement in concrete naturally forms an alkaline solution that protects the steel.Carbonation breaks down the passive layer of protection by lowering the pH level of the protective barrier. Chloride penetration acts as a catalyst to the corrosion process. It does not reduce the pH level like carbonation does, but instead directly damages the steel at weak points. A technique that has been popular in Europe is to install a waterproof membrane on the decks prior to the laying of the top layer of asphalt. (Not successful due to failure at joints and bends). A similar technique that has been tested is a highly-elastic acrylic rubber coating that can be applied over reinforced concrete surfaces. Lastly, as a prevention method penetrating sealers can be applied. These sealers keep chlorides out of the concrete, but allow water vapor to pass through the membrane. Once reinforced concrete has been contaminated by chlorides there are two alternatives outside of replacing it - repair or rehabilitation To repair chloride damage, one needs to merely replace or fix the contaminated parts. However, this only takes care of the symptoms, where rehabilitation essentially restores the concrete and reinforcement to their original condition. Another procedure for repairing reinforced concrete columns would be to employ a steel jacket. With this method, a steel jacket is placed around the exterior of the column and a grout is placed between the column's surface and the steel jacket to establish a secure bond. However, this is a short-term repair; the original corrosion problem needs to be recognized by either painting or galvanizing the steel jacket to ensure that it too will not corrode once exposed to deicing salts and other forms of chloride contaminants. Cathodic protection measures could also be used to avoid corrosion by using sacrificial metals which corrode themselves, stopping the corrosion in the rebars. Chloride extraction through high power electrical source could be carried out. Re-alkalization, aiding in increasing the pH of the concrete again while removing chlorides is the newest method and research is being carried out in the field. FRP is in the form of sheets or jackets to either restore damaged reinforced concrete to its original structural strength or in certain situations increases the original strength as well as improve confinement in seismic regions. However, FRP costs more than concrete and steel retrofits. This initial high cost is offset by several factors; lesser weight, reduced installation time, decreased maintenance and FRP's resistance to corrosion. The increase in life expectancy that results with the FRP wraps, the initial set-up costs are offset by a savings of 10-30 percent for a 75 year design life.

D. Disadvantages:

1) Cost:

The bigger disadvantage ofFiber Reinforcement Polymer (FRP) is cost approximately in all cases. The delivering cost of one kilo newtonFiber Reinforcement Polymer (FRP)in various parts of the world is totally depend upon distance and quantity. Steel cost has fluctuated widely in recent years so the relative cost also fluctuated. Generally people expect to pay three times as much for glass Fiber Reinforcement Polymer reinforcing bars, and up to ten times as much carbon fiber for prestressing tendons.

2) Flexibility:

Studies show that new fibers have stiffness that are comparable to those of metals, while showing much higher strengths. The result is that strains in these materials will be much higher if they are used at a reasonable fraction of the strength that one is paying so much for. Elastic strain capacities of the order of 1.5% - 2% are not uncommon, which compares with cracking strains in concrete of 0.01% and working strains in compression of about 0.1%. (The working strain capacity of steel rebar is about 0.2%.) So we have a bind; either we use the material at strains that are well below their capacity, in which case we are even more uneconomic, or we accept much higher curvatures, which is generally deemed to be unacceptable, if only to stop the public worrying about our structures.

3) Brittleness:

Not only do the fibers have high strain capacities, but when they do fail they are brittle. This has several corollaries. An assemblage of brittle materials is not as strong as the sum of its parts; when one element fails it sheds load to its neighbors, which can become overloaded in their turn. This is in marked contrast to an assembly of steel wires; when the weakest one reaches its capacity it yields and continues to carry some load, sometimes even strain hardening. The failure stress of a bundle of steel wires is pretty close to the average of its constituent parts, whereas the strength of an assemblage of brittle fibers is only a little above the strength of the weakest element. Brittle elements cannot be allowed to fail. A ductile structure taken close to failure can redistribute loads to other elements; in brittle structures they snap. Thus, we have to apply larger factors of safety to brittle materials because the consequence of overstressing is more severe. So once again we are being forced to be less economic than we otherwise would. We are often saved by the fact that structures with FRP are usually governed by stiffness rather than strength, but there are major exceptions.

4) Anchorage:

In order to get the forces into and out of Fiber Reinforcement Polymer (FRP) bars we have to be able to grip them. In the early days there was a huge literature dealing with bond, much of which proved a waste of time since too much bond is as bad as too little. It leads to localization of failure at concrete cracks; steel rebars rely on yield of the steel at critical cracks followed by de-bonding along the bar to reduce stress concentrations, but FRPs can’t yield so they snap. That can and has been quantified, but we still have problems gripping fibers for prestressing applications.

VIII. CONCLUSIONS

The fundamental problem for the use of Fiber Reinforced Polymer (FRP) in concrete remains the fact that it cannot be used as a direct replacement for steel. Significant amount of concrete in which an original design using steel bars or tendons has simply had them replaced by the equivalent amount of Fiber Reinforcement Polymer (FRP). This brief review of FRP has summarized the very broad range of unusual functionalities that these products. The functionality that allows these materials to perform under extreme conditions has to be balanced against process ability that allows them to be economically shaped into useful forms.

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