ORIGINAL RESEARCH PAPER

Engineering

FIBER REINFORCED POLYMERS (FRP) AND THEIR ENGINEERING APPLICATIONS

KEY WORDS: Fiber Reinforced Polymer, Carbon Fiber Reinforced Polymers, Durability, Freeze-thaw exposure, Fatigue behavior

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ABSTRACT

This paper explores the applications of fiber reinforced polymer (FRP) resins in the field of civil engineering. Carbon Fiber Reinforced Polymers (CFRP) are one of the advanced types of fiber reinforced polymer (FRP) composites in which different types of carbon fibers are used as the principal structural component. The CFRP is a reliable material in construction and civil engineering industry. It has high level of durability. Light weight proportion to size is its other chief advantage. The CFRP are not only used in civil engineering, but they are also widely used in the manufacture of consumer goods and industrial products. It is also used in aerospace industry. Since CFRP is light and very strong, it is used in the manufacturer of automotive, sail boats, computers, bicycles, sports goods and accessories such as tennis and badminton rackets, snooker sticks, boards etc. Higher level of durability characterized by great strength to weight is the major reason as to why the CRFP is considered as a favorite composite in aerospace industry.

I. Introduction:

Protecting structures from damages and enhancing their service life is a matter of serious concern in engineering. Therefore, a great deal of attention and time is spent by the researchers to develop adequate measures to prevent damage and enhance the live of engineering structures. This paper explores the applications of fiber reinforced polymer (FRP) resins in the field of civil engineering. Supporting the structures with different types of reinforced resin composites are one of the effective measures to protect engineering structures. Researchers have found that during the past few decades, the fiber reinforced polymer (FRP) has been used as one of the most affordable solutions to the corrosion problems of steel reinforcement in structural concrete (Ghosh, 2004; Tann & Delpak, 2003). The applications of FRP in new or damaged structures requires the development of design equations that must take into account the mechanical properties and the durability properties of FRP products.

II.I Application of Fiber Reinforced Polymers

The FRP have been used for confinement of reinforced concrete and masonry columns. Their high mechanical properties, light weight and low costs of installation have made them one of the most affordable ways of the column's confinement. Besides the high performance of FRP systems, there are quite a few concerns related to the long-term performance of wrapped columns, which have limited full performance of them. After cracking of the concrete core, the elastic pressure developed by the FRP jacket increases the strength and ductility of the unconfined column. External exposure conditions also referred to as environmental loading can vary widely from one location to another and also from one season to another (Balendran, Rana, Maqsood & Tang, 2002; Alampalli, 2005). The exposure condition can affect the properties, and consequently the structure of the wrapped elements. Environmental exposure consists of moist fluctuation, temperature cycles, freeze thaw effects, wet dry effects, ultraviolet radiation exposure and deicing salt. Strength, stiffness, and bond properties of FRP reinforcement that influence the response of concrete members are affected by environmental exposure (Walker, 2004**).** Tendency to be influenced by the environmental exposure include ultimate moment, deflection, crack width, energy absorption, and failure mode are **s**ome of the responses of FRP reinforced or strengthened concrete structures. Studies have shown that environmental cycles or immersion in solutions for durability, would affect the mechanical properties of FRP confined concrete (Green, 2007).

The degree of reduction in FRP properties under varying environmental conditions or even their damage depends on various factors such as type of fiber and resins, cure conditions, quality controls during manufacturing, and the severity of the external environmental agents such as PH. The type and quality of concrete influence the durability of FRP reinforced concrete members (Ghosh, 2002).

The studies on the durability performance of FRP, internally and externally, reinforced concrete members have received a huge attention recently. Several durability parameters have been investigated such as fatigue, creep, freeze thaw cycles, and the effects of high temperature and fire. Experience indicates that freeze-thaw exposure led to a decrease in the moment capacity and in the ultimate deflection of FRP externally strengthened beam. The decrease rate was larger for precracked specimen than for uncracked one (Robert, Cousin & Benmokrane, 2011). Freeze thaw exposure did not affect the flexural behavior of FRP bar reinforced concrete beam, however, the combined effect of the freeze thaw cycles leads to more brittle failure of FRP wrapped concrete cylinders than similar specimen kept at room temperature. Moreover, FRP wrapped concrete cylinders exposed to freeze thaw cycles show a significant increase in strength over unwrapped cylinders exposed to the same freeze thaw cycles. Increasing the number of FRP layers led to a bigger increase in strength (Robert, Cousin & Benmokrane, 2011).

The fatigue behavior of FRP reinforced concrete is an important durability issue. Studies on a pre-stressed concrete members indicated that the overall fatigue characteristics of FRP bars pre-tensioned concrete beams matched those of similarly loaded steel pre-tensioned beam. Fatigue behavior of FRP pre-tensioned beams in the post crack range resulted in much higher deflection and crack width than similar beams reinforced with pre-tensioned steel. The fatigue life of RC beams could be enhanced significantly through the use of externally bonded FRP reinforcement (Davids, Richie & Gamache, 2005; Zhou, 2004; Dutta, Lopez-Anido & Soon-Chul Kwon, 2007).

Limited studies have been conducted on the viscoelastic behavior of FRP. For externally reinforced concrete members, experimental studies have been conducted on both small and large scale FRP laminate bonded RC beam. Externally bonded FRP plates lead to a reduction in the time dependent deformation, and reduce the rate of compressive creep in the concrete of the strengthened systems. In terms of the FRP bar reinforced concrete beam the experiments indicate that the creep curve of FRP bar reinforced concrete beam is similar to that of steel reinforced members (Erdogmus, 2015; Halliwell, 2004). The creep deflection of FRP bar reinforced concrete beam could be predicated using the existing theory for steel reinforced concrete beams with a modification made for the creep coefficients of the FRP reinforced sections.

Limited theoretical and experimental studies have been conducted on the durability of the bonding between FRPs concrete structure. It was tested based on some parameter such as thermal effects, accelerated ageing tests, and an alkaline environment. For FRP internal reinforced concrete members, high temperature has detrimental effect on the bond due to the reducing shear stiffness in the FRP. Freeze thaw and wet dry cycle's exposure have a significant effect on the bond transfer length, shear stress distribution, and different strains between FRP and the concrete.

II. Carbon Fiber Reinforced Polymers (CFRP) and its Applications

Carbon Fiber Reinforced Polymers (CFRP) are one of the advanced types of reinforced composites in which different types of carbon fibers are used as the principal structural component. The CFRP is one of the most commonly used composites in the recent times to strengthen civil engineering structures and in the manufacture of industrial and consumer goods. The major reason as to why this polymer composite is used in various commercial and construction purpose is its efficiency and durability (Toutanji, Zhao & Isaacs, 2007; Bai, Kinuthia & Tann, 2005).

Several properties of CFRP determine the durability and performance of applied structures. The important features that affect the durability of CRFP include light weight, the ratio of strength-weight, the ratio of weight to elasticity, fatigue strength, corrosion resistance ability, lower coefficient of thermal expansion etc

The ratio of weight to strength is an important factor that determines its durability. The CFRP has high degree of strength compared to its weight. While CFRP is lighter than aluminum, it is stronger than iron. The elasticity of the composite is much higher than titanium. These features make it highly durable and effective composite compared to the other fiber reinforced polymers. Another important property that determines the durability is the ability to resist corrosion and abrasion. The CFRP is a highly corrosion resistant material. The composite also has degree of resistance to abrasion and strain that enables the structures to remain unaffected of wear and tear. The CFRP has high degree of resistance to heat as well. It does not shrink or expand when exposed to heat. The above features enhance the durability and life of the CFRP reinforced civil engineering structures and materials produced with CFRP (Toutanji, Zhao & Isaacs, 2007; Bai, Kinuthia & Tann, 2005).

The ability of the CFRP sheets to strengthen the concrete beams and their durability may vary according to the size of the beams. An experiment by Walker (2004) on the strengthening ability of CFRP indicated that the beams measuring B-8 on bonded well with CFRP sheets and gained about 19 percent of additional strength. The beams that sized B11- B13 experienced an enhanced strength of 109 percent. The horizontal application of CFRP was found to yield greatest strength than any other format. The anchorage of the strips on each side of the beams was the major cause of enhancement of strength.

The other important factors that affect the life of CFRP reinforced structures include the environmental and service load factors such as weather, chemical resistance, fatigue, dry-wet conditions etc. Environmental durability is of paramount importance in reinforcing the structures. Several types of reinforced structures are used to enhance the life of structures. It has been found that CRFP has much higher environmental durability as compared to other reinforces such as Glass Fiber Reinforced Polymer (GFRP) and Aramid Fiber Reinforced Polymers (AFRP). Experiments have shown that CFRP rods have high degree of resistance to chemical substances like chlorine, salts, alkali etc. While the strength of the adhesive bond between FRP and concrete structures deteriorates considerably during the freeze-thaw cycling in various chemical solutions like Na Cl, it remains stable in the case of CFRP. Immersion of CRFP rods in salt water for one year showed no reduction in its tensile strength or corrosion. This durability features makes CRFP an effective reinforcer for marine equipment. The CRFP has the ability of wet-curing of concrete structures when exposed to freeze-thaw conditions. This wet-cure property helps enhancing strength of the reinforced structures. It has been found that CFRP reinforced structures only lost about 9% of its ultimate strengths even after 100 freeze-thaw cycles in a 4 percent calcium solution, which is very impressive (Walker 2004; Toutanji, Zhao & Isaacs, 2007; Bai, Kinuthia & Tann, 2005; Appell, 2007).

The bonding behavior of CFRP is another useful advantage that influences its durability and application in construction industry. The Carbon fiber reinforced polymers have high quick-fix ability that is highly useful in repairing old bridges. The CFRP composites eliminate the use of rivets in repairing the old bridges. The Arizona University professors have developed a composite called CarbonWrap which is made of woven fibers of glass, carbon and Kelvar (Appell, 2007). It has been found that when these fibers are mixed in a resin matrix, the strength of substratum is enhanced significantly. When applied on the damaged bridges, it provided a tensile strength that is required to pull apart 200 tons per inch, the strength of which is almost 10 times more than steel. The application did not require the use of rivets in repair that normally reduces the strength. Moreover, the CarbonWrap was found to have great resistance to corrosion. It could withstand a pH solution for about 2 years. The application of CFRP laminates in repairing damaged bridges and civil engineering structures is worldwide. They are especially applied in the repair of buildings and bridges across the USA and Europe.

The tests conducted by the researchers of University of Rolla, Missouri on bridges of depression period in USA also revealed that CFRP could enhance the strength and life of concrete structures. The increase of strength could amount to about 25 percent. The different areas of damaged bridge in Missouri were braced with CFRP sheets. The areas of the bridge not wrapped with CFRP had 155kN capacity. But, when reinforced with CFRP composites, the strength was improved 200 kN capacity proving that the CRFP composites are extremely reliable (Bridges tests Reveal Strength of Composite Reinforcement, 1999).

The timber bond behavior of carbon fiber reinforced polymers is also impressive. Therefore, it is used as alternative in flexural strengthening of timber beams. In traditional methods the reinforcing planks are placed above the existing floor and are bonded them with wooden rods. But, CFRP laminates could be used as an innovative technique to strengthen the wooden floors. Since the bonding behavior of CFRP is very good, the CRFP laminates forms a thick bond with wooden substratum and enhance its strength leading to improved structure performance. The CRFP have other advantages in strengthening the timber beams. They are very light and easy to handle. Moreover, the CFRP laminates have good durability; therefore, do not require maintenance for long period of time (Herzog, Goodell, Lopez-Anido & Gardner, 2005).

The fatigue response of CFRP is excellent. Its fatigue resistance compared to other composites is superior. It has been reported that the girders and concrete structures repaired with CFRP showed no deterioration in its strength even under high cycle fatigue. The experiments conducted at the University of Wyoming have revealed that CFRP rods could sustain 100,000 of loads between 60 and 70 percentages of their ultimate tensile efficiency. The reinforcement technique using pre-stressed CFRP is found to provide extremely good results. The fatigue resistance of polymer composites is directly related to the type of fiber that is expressed in terms of amplitude, stress number of cycles and mean. The composite made of carbon seem to have greater fatigue ability than other fibers. The concrete structures repaired with pre-stressed CRFP showed improved rigidity and strength as well as greater resistance for crack development. Moreover, this technique could reach maximum degree of bonding and de-bonding failures are very unlikely that makes CRFP as highly effective and durable materials (Dutta, Lopez-Anido, & Soon-Chul Kwon, 2007; Davids, Richie & Gamache, 2005).

There are other evidences to robust and superior fatigue behavior of CFRP. In an experiment by Chawla and Chawla (2005) on fatigue behavior of various composites indicated that CFRP have higher levels of resistance to fatigue. The carbon fibers that were cycled to about 98 percent of their tensile strength did not show any evidence of fatigue failure. The carbon fibers developed by thermal decomposition of poly-acrylonitrite yields enhanced strength. This process ennobles the carbon fibers achieve tensile strength of almost 800,000 psi and a modulus of about 40million psi.

The durability of CFRP has great utility in power plants and water systems. The conventional water pipes, especially those placed underground, are likely to get damaged, and get burst causing loss to several millions dollars. Corrosion is the major cause for this problem. The corrosion resistant ability of CFRP has great advantage in this situation. Corrosion of underground water pipes could be significantly reduced if CFRP sheets were internally lined with CFRP sheets. Such pipes are less likely to be burst and tend to last longer than un-reinforced pipes (Balendran, Rana, Maqsood & Tang, 2002).

In ordinary temperature climatic conditions, the CFRP's ability to strengthen structures is quite outstanding. However, it does not yield good results in extreme climatic conditions. It has been seen that in colder climatic conditions, CFRP may not provide good durability to its substrate structures. In colder conditions it becomes brittle, hence is not suggested its applications. Yet, the research conducted by Queensland researchers on the efficiency of CFRP in colder environment is quite encouraging. The researchers examined the performance of concrete beams measuring 100 X 150 X1200 strengthened with different types of fiber reinforced polymers in colder region. The beams were subjected to 300 freeze-thaw cycles. It was found that the concrete beams strengthened with CRFP did not show any significant deterioration in their freeze-thaw resistance. The freeze-thaw behavior and load ability of the beams reinforced with CFRP remained relatively unaffected in such condition (Green, 2007).

III. Conclusion

The CFRP is a reliable material in construction and civil engineering industry. It has high level of durability. The CFRP are not only used in civil engineering, but they are also widely used in the manufacture of consumer goods and industrial products. Since CFRP is light and very strong, it is used in the manufacturer of automotive, sail boats, computers, bicycles, sports goods and accessories such as tennis and badminton rackets, snooker sticks, boards etc. The CRFP is also used in aerospace industry. Higher level of durability characterized by great strength to weight is the major reason as to why the CRFP is considered as a favorite composite in aerospace industry.

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