Fibre Reinforced Polymer (FRP) in Civil, Structure & Geotechnical Engineering

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ABSTRACT

This paper presents the role general of Fiber Reinforced Polymer (FRP) in aspects of civil, structure and geotechnical engineering. In geotechnical engineering is important where corrosion is of problem, such as permanent soil anchors or reinforcement bars and rods. FRP have straightforward applications in retaining walls installation in soil with out concrete & foundation, sea wall and tunnel. The state in civil engineering has been slower, but it has been used to replace steel in reinforced or pre-stressed concrete structures.

KEYWORDS

FRP , Geotechnical , Civil , Structures , Anti-corrosion

INTRODUCTION

For years, civil engineers have been in search for alternatives to steels and alloys to combat the high costs of repair and maintenance of structures damaged by corrosion and heavy use. For example, cost estimates for maintenance of highway bridge decks composed of steel-reinforced concrete are up to $96 billion/year. Since the 1940s, composite materials, formed by the combination of two or more distinct materials in a microscopic scale, have gained increasing popularity in the engineering field. Fiber Reinforced Polymer (FRP) is a relatively new class of composite material manufactured from fibers and economical for the development and repair of new and deteriorating structures in civil engineering. The mechanical properties of FRP make them ideal for widespread applications in construction worldwide.

This new technology has already found important applications in aerospace, military and sports industry. The civil engineering industry benefits from a variety of applications from reinforced and pre-stressed concrete, soil reinforcement for walls and tunnels and also columns, joints, etc. But the type of composites to be dealt herewith are high strength geosynthetic bars, tendons and tubes that can be used for soil and rock reinforcement and anchors. They will be called FRP geobars and geotubes. FRPs are commonly used in the aerospace, automotive, marine, geotechnical applicants and construction industries.

WHAT'S FRP?

Materials produced with the above-mentioned methodology are often generically referred to as composites. The choice of matrix can have a profound effect on the properties of the finished composite. One method of producing graphite-epoxy parts is by layering sheets of carbon fiber cloth into a mold in the shape of the final product. The alignment and weave of the cloth fibers is chosen to optimize the strength and stiffness properties of the resulting material. The mold is then filled with epoxy and is heated or air cured. The resulting part is very corrosion-resistant, stiff, and strong for its weight. Parts used in less critical areas are manufactured by draping cloth over a mold, with epoxy either preimpregnated into the fibers or "painted" over it. High performance parts using single molds are often vacuum bagged and/or autoclave cured, because even small air bubbles in the material will reduce strength.

Fibre-reinforced plastic (FRP) (also fibre-reinforced polymer) are composite materials made of a polymer matrix reinforced with fibres. The fibers are usually fiberglass, carbon, or aramid, while the polymer is usually an epoxy, vinylester or polyester thermosetting plastic.
The fiber is an important constituent in composites. A great deal of paper and development has been done with the fibers on the effects in the types, volume fraction, architecture, and orientations. The fiber generally occupies 30% - 70% of the matrix volume in the composites. They can be chopped, woven, stitched, and/or braided. They are usually treated with sizings such as starch, gelatin, oil or wax to improve the bond as well as binders to improve the handling. The most common types of fibers used in advanced composites for structural applications are the fiberglass, aramid, and carbon. The fiberglass is the least expensive and carbon being the most expensive. The cost of aramid fibers is about the same as the lower grades of the carbon fiber. "Other high-strength high-modulus fibers such as boron are at the present time considered to be economically prohibitive."

• **Glass Fibers**

The glass fibers are divided into three classes -- E-glass, S-glass and C-glass. The E-glass is designated for electrical use and the S-glass for high strength. The C-glass is for high corrosion resistance, and is uncommon for civil engineering application. Of the three fibers, the E-glass is the most common reinforcement material used in civil structures. It is produced from lime-alumina-borosilicate which can be easily obtained from abundance of raw materials like sand. The fibers are drawn into very fine filaments with diameters ranging from 2 to 13 X 10^{-6} m. The glass fiber strength and modulus can degrade with increasing temperature. Although the glass material creeps under a sustained load, it can be designed to perform satisfactorily. The fiber itself is regarded as an isotropic material and has a lower thermal expansion coefficient than that of steel.

<table>
<thead>
<tr>
<th>Typical Properties</th>
<th>E-Glass</th>
<th>S-Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>2.60</td>
<td>2.50</td>
</tr>
<tr>
<td>Young's Modulus (GPa)</td>
<td>72</td>
<td>87</td>
</tr>
<tr>
<td>Tensile Strength (GPa)</td>
<td>1.72</td>
<td>2.53</td>
</tr>
<tr>
<td>Tensile Elongation (%)</td>
<td>2.4</td>
<td>2.9</td>
</tr>
</tbody>
</table>

• **Aramid Fibers**

These are synthetic organic fibers consisting of aromatic polyamides. The aramid fibers have excellent fatigue and creep resistance. Although there are several commercial grades of aramid fibers available, the two most common ones used in structural applications are type 1 and type 2. The Young's Modulus curve for type 1 is linear to a value of 83 GPa but then becomes slightly concave upward to a value of 100 GPa at rupture; whereas, for type 2 the curve is linear to a value of 124 GPa at rupture (see Table 2). As an anisotropic material, it's transverse and shear modulus are an order of magnitude less than those in the longitudinal direction. The fibers can have difficulty achieving a chemical or mechanical bond with the resin.

<table>
<thead>
<tr>
<th>Typical Properties</th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.44</td>
<td>1.44</td>
</tr>
<tr>
<td>Young's Modulus (GPa)</td>
<td>83/100</td>
<td>124</td>
</tr>
<tr>
<td>Tensile Strength (GPa)</td>
<td>2.27</td>
<td>2.27</td>
</tr>
<tr>
<td>Tensile Elongation (%)</td>
<td>2.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>

• **Carbon Fibers**

The graphite or carbon fiber is made from three types of polymer precursors -- polyacrylonitrile (PAN) fiber, rayon fiber, and pitch. The tensile stress-strain curve is linear to the point of rupture. Although there are many carbon fibers available on the open market, they can be arbitrarily divided into three grades as shown in Table 3. They have lower thermal expansion coefficients than both the glass and aramid fibers. The carbon fiber is an anisotropic material, and its transverse modulus are an order of magnitude less than its longitudinal modulus. The material has a very high fatigue and creep resistance.
Table 3

<table>
<thead>
<tr>
<th>Typical Properties</th>
<th>High Strength</th>
<th>High Modulus</th>
<th>Ultra-High Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0 - 2.1</td>
</tr>
<tr>
<td>Young's Modulus (GPa)</td>
<td>230</td>
<td>370</td>
<td>520 - 620</td>
</tr>
<tr>
<td>Tensile Strength (GPa)</td>
<td>2.48</td>
<td>1.79</td>
<td>1.03 - 1.31</td>
</tr>
<tr>
<td>Tensile Elongation (%)</td>
<td>1.1</td>
<td>0.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Since its tensile strength decreases with increasing modulus, its strain at rupture will also be much lower. Because of the material brittleness at higher modulus, it becomes critical in joint and connection details, which can have high stress concentrations. As a result of this phenomenon, carbon composite laminates are more effective with adhesive bonding that eliminates mechanical fasteners.

Main advances of FRPs

- High and adjustable tensile strength
- High and adjustable Young's modulus
- High dynamic strength
- Excellent corrosion resistance
- Low unit weight
- Magnetic and electric neutrality
- High tensile strength
- Low weight (little change to the mass of structure means no foundation adjustments required)
- Corrosion resistance
- Thermal compatibility with common construction materials, e.g. concrete
- Excellent fatigue behavior
- Fast speed of construction
- Products are light and can be handled without the need for any lifting equipment on job site
- Versatility to be applied to non-flat surfaces
- Odorless (extremely important when the structure is occupied)
- Low cost

FLEXURAL STRENGTH

The flexural (or bending) capacity of structural members can be easily enhanced by bonding a layer of FRP to the tension face of the element. In the case of a reinforced concrete structure, for example, the FRP resists tension forces that supplement the tension force being resisted by the existing reinforcing steel. Thus, the moment capacity of the member is calculated by taking into account the contributions of both steel and FRP.

SHEAR STRENGTH

Shear strength in concrete is resisted by diagonal tension; it is this principle that allows FRP to be used as shear reinforcement. Bonding fabrics of FRP to the sides of a reinforced concrete beam, for example, allow the fibers of the fabric (which are parallel to the legs of the stirrups of the beam) to resist tension, and thus shear forces. Most design guidelines limit the allowable strain in the FRP for shear to very small values; this is to ensure that the shear crack does not become too wide and that the aggregate interlock remains present.

AXIAL STRENGTH

The fibers of FRP buckle at relatively small loads; thus, most design guidelines do not allow direct contribution of the FRP to axial load enhancement. However, when a concrete column is wrapped with FRP, the confinement provided by the FRP increases both the strength and the failure strain (ductility) of the column. It is this contribution that can enhance the overall axial strength of the member.

DEFLECTION

The presence of FRP can reduce deflections under service loads.
DUCTILITY
For columns, where the FRP is primarily used for confinement, the ductility of the members is significantly enhanced. For flexural members, however, the gain in strength is often accompanied by a reduction in deflection at failure (i.e. ductility). Nevertheless, by proper design, one can ensure that the steel reinforcement in the beam yield before failure, giving advanced warning prior to failure of the beam.

CORROSION
FRP products are very effective in repair of corrosion-damaged structures. Because oxygen is the fuel for the corrosion process, by totally encasing a member in FRP, this fuel is shut off. This will significantly reduce the rate of corrosion. At the same time, FRP products can be used to repair and strengthen structures where corrosion has reduced the area of steel reinforcement.

FRP LAMINATE STRUCTURE
FRPs are typically organized in a laminate structure, such that each lamina (or flat layer) contains an arrangement of unidirectional fibres or woven fibre fabrics embedded within a thin layer of light polymer matrix material. The fibres, typically composed of carbon or glass, provide the strength and stiffness. The matrix, commonly made of polyester, Epoxy or Nylon, binds and protects the fibers from damage, and transfers the stresses between fibers.

SUITABILITY OF FRP FOR USES IN STRUCTURAL ENGINEERING
The strength properties of FRPs collectively make up one of the primary reasons for which civil engineers select them in the design of structures. A material's strength is governed by its ability to sustain a load without excessive deformation or failure. When an FRP specimen is tested in axial tension, the applied force per unit cross-sectional area (stress) is proportional to the ratio of change in a specimen's length to its original length (strain). When the applied load is removed, FRP returns to its original shape or length. In other words, FRP responds linear-elastically to axial stress. The response of FRP to axial compression is reliant on the relative proportion in volume of fibers, the properties of the fiber and resin, and the interface bond strength. FRP composite compression failure occurs when the fibers exhibit extreme (often sudden and dramatic) lateral or sides-way deflection called fiber buckling. FRP's response to transverse tensile stress is very much dependent on the properties of the fiber and matrix, the interaction between the fiber and matrix, and the strength of the fiber-matrix interface. Generally, however, tensile strength in this direction is very poor. Shear stress is induced in the plane of an area when external loads tend to cause two segments of a body to slide over one another. The shear strength of FRP is difficult to quantify. Generally, failure will occur within the matrix material parallel to the fibers.

Among FRP's high strength properties, the most relevant features include excellent durability and corrosion resistance. Furthermore, their high strength-to-weight ratio is of significant benefit; a member composed of FRP can support larger live loads since its dead weight does not contribute significantly to the loads that it must bear. Other features include ease of installation, versatility, anti-seismic behaviour, electromagnetic neutrality, excellent fatigue behavior, and fire resistance. However, like most structural materials, FRPs have a few drawbacks that would create some hesitancy in civil engineers to use it for all applications: high cost, brittle behavior, susceptibility to deformation under long-term loads, UV degradation, photo-degradation (from exposure to light), temperature and moisture effects, lack of design codes, and most importantly, lack of awareness.

APPLICATIONS OF FRP COMPOSITES IN CONSTRUCTION
There are three broad divisions into which applications of FRP in civil engineering can be classified: applications for new construction, repair and rehabilitation applications, and architectural applications. FRPs have been used widely by civil engineers in the design of new construction. Structures such as bridges and columns built completely out of FRP composites have demonstrated exceptional durability, and effective resistance to effects of environmental exposure. Pre-stressing tendons, reinforcing bars, grid reinforcement, and dowels are all examples of the many diverse applications of FRP in new structures.

One of the most common uses for FRP involves the repair and rehabilitation of damaged or deteriorating structures. Several companies across the world are beginning to wrap damaged bridge piers to prevent collapse and steel-reinforced columns to improve the structural integrity and to prevent buckling of the reinforcement. Architects have also discovered the many applications for which FRP can be used. These include structures such as siding/cladding, roofing, flooring and partitions.
FRP FOR USES GEOTECHNICAL ENGINEERING

Strengthening existing masonry walls and repairing damaged masonry walls can be accomplished utilizing any of a number of popular techniques. For many years these methods have included surface overlays of various coatings including shotcrete; grout injection with and without reinforcing bars in the cells; and external stiffening including steel and timber bracing elements (FEMA 1997). The popularity of these techniques results from the facts that designers, contractors, and building officials are familiar with the behavior of these materials and with the specifications governing their design and construction. In the past 10-15 years, another type of retrofit and repair method has gained acceptance. This method involves the use of fiber reinforced polymers (FRP’s), or, as described in this paper, carbon fiber reinforced polymers (CFRP’s), as a strengthening overlay on structural components.

Extensive research has been performed on these materials applied to masonry walls with early research conducted by Seible et al. (1990) on FRP retrofit methods for unreinforced masonry (URM) walls. His results along with those from masonry research conducted by Al-Chaar & Hassan (1999), Ehsani & Saadatmanesh (1996), Ehsani et al. (1997), Triantafillou (1998), Gilstrap & Dolan (1998), and Marshall et al. (1999) revealed that shear and flexural strength in masonry walls can be increased through the use of FRP composites externally attached to these masonry elements.

In most applications, strengthening and repair methods on masonry walls require the increased capacity or the wall be accompanied by an increased capacity of the connection between the wall and its supporting member or foundation. In the traditional methods described above, the connection is strengthened by anchoring the repair materials to the foundation. These anchors often are provided by drilling, grouting, injecting epoxy adhesives, clamping with steel angles or channels, or adding additional concrete or masonry material. Currently, if strengthening or repairs to masonry walls are provided by CFRP laminates, then the connection is strengthened using these same traditional anchoring methods. Alternatively, anchoring techniques utilizing the CFRP material itself need to be developed.

Ground and rock anchors are used to stabilize tunnels, rock faces, cuttings and slopes. A pre-stressed tendon or cable installed inside a borehole applies a restraining force to the rock face or slope via a plate. The end of the tendon is grouted or locked mechanically deeper into sound strata. Ground anchors can also be used to provide support to retaining walls. Soil nails work on a similar principal and are used for slope stabilization. The use of FRP tendons instead of steel offers advantages of low weight, ease of handling and corrosion resistance, with the ability to use conventional jacking systems. FRPs have a lower modulus of elasticity than steel, thus load loss due to relaxation of the anchorage system is lower.

CONCLUSIONS

FRP materials offer an effective solution to the problem of structure in aggressive environments and where the magnetic are undesirable. They also appear to be suitable for the manufacturing of nonstructural pre-cast elements where the weight of the reinforcement and structure required is a disadvantage. Using FRPs allows a drastic cut down of the overall weight of the elements and facilitates handling and installation procedures. FRP geobars and geotubes present high tensile strength, low unit weight, high resistance to corrosion, easy cuttability, but the cost is high as compared to steel. Its replacement will occur where corrosion or demolition is a major concern.

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