APPLICATION OF FIBER REINFORCED PLASTICS OR POLYMERS IN CIVIL ENGINEERING STRUCTURES

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Abstract
Engineers throughout the world including India have used FRP to solve their structural problems in an efficient and economical manner. In the field of Civil Engineering, most of the use of FRP is confined to repairing and strengthening of structures. FRPs offer an added advantage over conventional materials and methods of retrofitting. Like other materials, FRP also has its limitations. After presenting a brief review on these dimensions, this paper provides thorough information on the compatibility and application of FRP in Civil Engineering in India.

1. General Introduction of FRP
Fiber-Reinforced Plastic (FRP), also known as Fiber-Reinforced Polymer is a composite material made of a polymer matrix reinforced with high strength fibers. Matrix is the original plastic material without fiber reinforcement. The matrix is a tough but relatively weak plastic that is reinforced by stronger stiffer reinforcing filaments or fibers. The fibers in an FRP composite are the main load-carrying element and exhibit very high strength and stiffness when pulled in tension. The extent that strength and elasticity are enhanced in a fiber reinforced plastic depends on the mechanical properties of the fiber and matrix, their volume relative to one another, and the fiber length and orientation within the matrix. Reinforcement of the matrix occurs by definition when the FRP material exhibits increased strength or elasticity relative to the strength and elasticity of the matrix alone. The fibers are usually glass, carbon or aramid, although other fibers such as paper or wood or asbestos also are sometimes used. FRPs are commonly used in the aerospace, automotive, marine and construction industries.

1.1 Beginning of FRP
The idea of combining two different materials to make a single, superior composite material is not new. Some of the earliest building materials were composite materials. The ancient Egyptians reinforced their mud bricks with straw to make them stronger. Fiber Reinforced Polymers (FRPs) are just the latest version of this very old idea. Commercially, it started as early as 1909 with Bakelite. The development of fiber reinforced plastic for commercial use was extensively researched in the 1930s particularly of interest to the aviation industry. With the continuing cost reduction in high-performance FRP materials and the growing need for new materials to renovate civil infrastructures, FRP materials are now finding wider acceptance among civil engineers.

1.2 The Evolution of Composites in Civil Engineering
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 $90 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 resins and has proven efficient and economical for the development and repair of new and deteriorating structures in civil engineering. The mechanical properties of FRPs make them ideal for widespread applications in construction worldwide.

1.3 FRP Laminate Structure
FRP are typically organized in a laminate structure such that each lamina (or flat layer) contains an arrangement of unidirectional fibers or woven fibers embedded within a thin layer of light matrix material. The fibers 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, ensures that the fibers remain aligned, and allows loads to be distributed among many of the individual fibers in the composite.
2. Why FRP in Structural Engineering

1. 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.

2. 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 structure 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).

3. 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.

4. 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.

5. 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 behavior, electromagnetic neutrality, excellent fatigue behavior, and fire resistance.

3. Limitations

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. FRP composite compression failure occurs when the fibers exhibit extreme (often sudden and dramatic) lateral or sides-way deflection called fiber buckling. 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.

4. Applications of FRP Composites in Construction

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. Glass fibers begin as varying combinations of SiO₂, Al₂O₃, B₂O₃, CaO, or MgO in powder form. Carbon fibers are created when polyacrylonitrile fibers (PAN), Pitch resins, or Rayon are carbonized (through oxidation and thermal pyrolysis) at high temperatures. Aramid fibers are most commonly known Kevlar, Nomex and Technora. Aramids are generally prepared by the reaction between an amine group and a carboxylic acid halide group (aramid). 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.

There are three broad divisions into which applications of FRP in Civil Engineering can be classified:

1. Applications for new construction
2. Repair and rehabilitation applications
3. Architectural applications

4.1 Applications for new construction

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. The technique of externally bonding FRP to reinforced concrete (RC) structures was introduced into China in 1997. In India, field
application of FRP for structural strengthening could be traced as early as in 1999. However, FRP is being used for new construction also in many countries; nothing significant could be traced in India. The material is still considered relatively new in this part of the world. Other countries like China is working on use of FRP in new construction in many directions like FRP bridges, FRP space structure, and concrete filled FRP tube columns. There exist many FRP footbridges in China.

5. Repair and Rehabilitation Applications
Construction is a major part of development plan of developing countries including India. To meet the large demand for infrastructure development, maintenance and life enhancement of existing structures are very important. After many years of use, an existing structure often needs to be repaired or upgraded because of so many reasons like damage due to corrosion or increased load demand etc. There are several methods for retrofitting of structures like guinting, post tensioning, externally bonded steel plates, steel or concrete jackets etc. Epoxy injection and newly developed methods like advanced techniques for corrosion affected RCC and methods of modifying structural properties using active or passive mass damper for high rise buildings are also there. 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.
FRP is now being used in our industry to strengthen concrete, steel and masonry structures. They compete directly with traditional strengthening techniques like section enlargement, external post-tensioning and steel plate bonding. Steel plate bonding is a method of strengthening a structure by bonding steel plates to the concrete surface in the areas of high tensile stresses.

5.1 Architectural Applications
Architects have also discovered the many applications for which FRP can be used. These include structures such as siding/cladding, roofing, flooring and partitions. In Canada, ISIS, Intelligent Sensing for Innovative Structures, is a program that consists of collaborative efforts of universities in various disciplines with primary mission to develop the innovative use of FRPs in concrete structures.

6. Examples of FRPs Use in Civil Engineering
6.1 Structural Reinforcement
Composite system consisting of carbon fiber, aramid or glass impregnated in-situ with the polymer matrix, is used for the reinforcement of elements in concrete, masonry, wood and steel. Among many other applications, concrete and masonry walls may be strengthened to better resist seismic and wind loads, concrete pipes, silos and tanks may be lined with FRP to resist higher internal pressures. Glass FRP (GFRP) and Aramid FRP (AFRP) are excellent for seismic upgrades. In cases where stresses are sustained in the FRP (such as in bending and shear strengthening), GFRP is avoided because of creep rupture effects. Carbon FRP is much more suitable and durable in these situations.

6.2 Reinforcement in Corrosive Environment
Corrosion of steel reinforcements reduces the durability of concrete structural elements, leading to serious maintenance costs. Fields of application for GFRP products in corrosive environment are in: harbors, seaside walkways, offshore structures, water treatment plants, sewage structures, rehabilitation of final lining of tunnels.

6.3 Synthetic Fibers for FRC
GFRP composite fibers are technically very good alternative to standard fibers for concrete reinforcement made of steel or plastic materials. They have high tensile strength, can be distributed evenly in the concrete without compromising the workability of the same, have high resistance to chemical corrosion and electrostatic, are non-magnetic, have lightness of handling and deployment.

6.4 Structural Reinforcement of Historical Buildings
For several years, innovative materials are applied in the architectural renovation of historic buildings. FRP materials (carbon, aramid and glass) are an alternative consolidated in recovery and reinforcement of buildings of traditional value. The lightness combined with high mechanical performance makes it particularly effective when compliance with the existing and little invasiveness is essential for the success of the intervention.
6.5 Shear Connectors
In concrete paving expansion joints are necessary in order to control the propagation of cracks caused by the withdrawal of the concrete and the thermal expansion. Joints artificially create lines of weakness in the concrete. Connectors’ fiberglass return shear strength along the joint.

6.6 Connectors for Pre-cast Concrete
The growing need to produce pre-cast high performance, led the industry to turn to technology for synthetic elements or FRP of high durability, low costs with excellent isolation heat.

7. Scope of FRP in India
The overall composites market in India is relatively small, compared to per capita consumption in other parts of the world. A few years ago consumption level of composites in India was only about 30,000 MT, as compared to about 2,00,000 MT in many other parts of the world including China. There is enormous scope of use of FRP in India, because of seismically deficient buildings, long coast line and long monsoon season pressing the use of non-corrosive FRP. Traditional materials, such as wood, are in short supply. There are a few examples of FRP application for retrofitting before Gujarat earthquake (2001) and after this earthquake only, the technique is gaining attention in India. However, the same is not to the extent warranted by potential of the FRP that exist. As the material is still considered relatively new in India, most of the works had been carried out in accordance to available guidelines and published literature. In spite of all the potential of India, rapid use of FRP in civil infrastructure is difficult because of local code restrictions. There is an urgent need to develop Indian standards for use of FRP and more production facilities. With less than 5% of the Asian FRP market, there is plenty of room for growth in India. To improve this situation, Civil Engineering and their extension programs must provide sufficient training on unique features of FRPs so that engineers could design or specify them in construction. At this juncture, there is a need of Government- Industry-Institute partnership to exploit full potential of FRP. The increase in use of FRP for retrofitting is inevitable because of its potential.

7.1 Research and Developments of FRP in India
In India, in the field of education and research related to FRP in construction, IIIts, IISc, Structural Engineering Research Center (SERC) Chennai, FRP institute Chennai, Indian Society for Advancement of Materials and Process Engineering (ISAMPE) (headquarter- Bangalore), Research Design and Standards Organization (RDSO) under the Ministry of Railways at Lucknow, Technology Information Forecasting and Assessment Council (TIFAC) a unit of DST, Composites Technology Centre (at IITM) are among others, participating actively. For the composites industry a monthly magazine-'FRP Today’ is being published in India since the year 2000. The Department of Science and Technology, Government of India, in collaboration with the universities, is developing standards for FRP in construction. Focus is placed on the rate of degradation of glass FRP in view of the South Asian environment and the concrete mix typically used in India. The application is targeted at corrosion damaged structures and seismic retrofitting. Composites Technology Centre (formerly -Fiber Reinforced Plastics research Centre) was established in 1974 at IITM as an interdisciplinary Centre for carrying out teaching, research, design and development in the field of composite materials and their applications. The Centre was renamed as Composites Technology Centre in 1997.

7.2 Civil Engineering Applications of FRP in India
There are many Indian projects to the credit of FRP systems by various companies like Fyfe (India) Pvt Ltd, Fosroc Chemicals (India) Pvt Ltd, Krishna Conchem Products Pvt Ltd, BASF, Sika India Pvt Ltd etc. There are now well developed design methods for many applications like RC structures using FRP bars, but perhaps there has been no application so far, because there is not much demand in construction compared to FRP strengthening. Many projects have been completed by above mentioned companies from 1999 to strengthen the deteriorated structures of importance.

Some of the representative Civil Engineering applications of FRP in India in the beginning include:
Structural strengthening of circular columns and flat slabs at Shah House, Worli, Mumbai in August 1999, Slab strengthening at Sudhakar building Mumbai in September 1999, Structural strengthening of various MTNL buildings Mumbai in 2000, Structural strengthening/ protection/corrosive protection of St. Thomas school New Delhi in 2001, Localized strengthening of beam-column junctions at Reserve Bank of India Staff quarters Mumbai in 2002, Strengthening of columns due to low grade concrete at IT Software Park Hyderabad in 2004 etc. There are many strengthening works going on in Hyderabad, Bangalore and Pune. There are Indian applications of Tyfo Fiber wrap System in Bridges, water tanks, brick walls in Goa, Delhi and Ahmadabad. There are some Indian projects where Nitowrap by Fosroc and Sikawrap from Sika India Pvt Ltd has been used. One of the major applications of FRP has been in earthquake damaged structures in Gujarat.
8. Disposal and Recycling of FRP

Plastics pose a particular challenge in recycling processes because they are derived from polymers and monomers that often cannot be separated and returned to their virgin states, for this reason not all plastics can be recycled for re-use. Fiber reinforced plastics and their matrices share these disposal and environmental concerns. In addition to these concerns, the fact that the fibers themselves are difficult to remove from the matrix and preserve for re-use means FRP amplify these challenges. FRP are inherently difficult to separate into base material that is into fiber and matrix, and the matrix into separate usable plastic, polymers, and monomers. These are all concerns for environmentally informed design today, but plastics often offer savings in energy and economic savings in comparison to other materials, also with the advent of new more environmentally friendly matrices such as bio plastics and uv-degradable plastics, FRP will similarly gain environmental sensitivity.

9. Conclusion

The Civil Engineering structures continues to face numerous challenges, i.e., increasing growth demands and heavier loads as well as trying to preserve aging and rapidly deteriorating structural elements. As we enter into a new millennium, our strategy is to stay ahead of the structural deterioration curve by focusing on the use of emerging high performance structural materials and innovative quality designs for more durable and reliable structures.

Through this pursuit and among many other emerging new materials, the fiber reinforced polymer (FRP) composite technology has been demonstrated with great success for structural applications. It has been found that the characteristics of a composites element or system can be tailored and designed to meet any desired specifications. The highly corrosion and fatigue resistance composites materials are making inroads into the civil infrastructure industry. These outstanding composites are among the leading materials in structural engineering applications today. The text within this volume will support the following conclusions:

- Fiber reinforced composite plate bonding offers significant advantages over steel plate bonding for the vast majority of strengthening applications.
- Fiber reinforced composite is so versatile that the range of applications for which external reinforcing is appropriate will increase significantly.
- No construction or repair method involving structural analysis and deterioration mechanisms can be said to be completely understood, including all of those currently in everyday use. However, FRP has been sufficiently researched to enable the techniques to be applied confidently on site, providing care is taken.
- The masonry walls strengthened with carbon-FRP composites results in increase of 24 times the unreinforced capacity in vertical bending and 7 times in horizontal bending. Use of FRP is greatly accepted and established as structural reinforcement (of historical buildings, in corrosive environment etc.), connectors for shear, pre-cast etc.

10. References

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