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APPLICATION OF POLYMER COMPOSITES IN CIVIL ENGINEERING

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ABSTRACT

There is a growing concern with worldwide deterioration of traditional materials such as concrete, steel, and timber. Recently, attention has shifted to the use of fiber reinforced polymer composites (FRPs) as alternative materials. Polymers provide huge opportunities for the advancement of materials research, the improvement of material property, and the strengthening structures damaged, recycling wastes in civil engineering. The utilisation of polymers in Geotechnical Engineering (a sub-discipline within civil engineering which covers broadly all forms of soil or the earth's crust related problems) constitutes a major range of applications for these materials. The term geosynthetic has been coined to describe the synthetic polymers, almost exclusively thermoplastics, used for geotechnics problems including environmental geotechnology. The construction sector is one of the world's largest consumers of polymer composites. Unreinforced polymer composite materials have been used by the construction industry for many years in non-load bearing applications such as trimmings, kitchenware, vanities and cladding. In the last decade there has been a concerted effort to migrate reinforced polymer composites (RPCs) into the construction industry for use in primary load bearing applications. Potential advantages commonly expounded by proponents of RPC materials include high specific strength, high specific stiffness, tailor able durability, good fatigue performance, versatile fabrication and lower maintenance costs. As a result reinforced polymer composites are being investigated in applications such as rehabilitation and retrofit, alternative reinforcement for concrete and, in rare cases, entire fiber composite structures. However, this paper proposes that as issues of sustainability become increasingly important to material choice, some fibre composite materials could be at an advantage over traditional materials. This paper is intended to present and discuss breakthrough technological developments which are expected to revolutionize applications in civil engineering.

***Keywords:* polymer composites, fiber composites, natural fiber composites, bio-composites, construction materials, advanced materials, reinforced plastics, civil structures.**

I. INTRODUCTION

Civil engineers should acquire profound knowledge on chemical, physical and mechanical behavior of the different types of polymers as well as their application and possible damages in construction. This will allow them to make suitable decisions for materials for the case on hand as well as to avoid damages during the planning and execution.

The main focus should be on:

- Composition of polymer composits
- Production and processing of polymers including aspects of energy balance
- Strength and deformation behavior
- Physical qualities
- Chemical resistance
- Ageing and weather conditions
- Special features concerning the application of polymers in the field of new buildings and restoration
- Damages in polymers and how to avoid them

Different applications of fiber reinforced polymer composites (FRPCs) for external strengthening in civil construction are reviewed in this paper. Experimental as well as analytical and numerical research contributions have been focused in the review. The main structural components such as beams, columns and beam-column joints, have been reviewed and structural behavior of each component is discussed briefly.

As FRPs are non-corrosive, high strength and modulus values compared to their density, light weight, acceptable deformability, tailored design and excellent formability enable the fabrication of new elements and the structural rehabilitation of the existing parts made of traditional materials. Furthermore, the resistance of FRP materials to corrosion means that they can be used to replace steel and reinforced concrete in situations when they would be exposed to corrosion. FRP therefore has wide application prospects in civil engineering ranging from reinforcing rods and tendons, wraps for seismic retrofit of columns and externally bonded reinforcement for strengthening of walls, beams, and slabs, to all-composite bridge decks, and even hybrid and all-composite structural systems.

II. FRP COMPOSITE

A Fiber Reinforced Polymer (FRP) composite is defined as a polymer (plastic) matrix, either thermo set or thermoplastic, that is reinforced (combined) with a fibre or other reinforcing material with a sufficient aspect ratio (length to thickness) to provide a discernable reinforcing function in one or more directions. FRP composites are different from traditional construction materials such as steel or aluminium. FRP composites are anisotropic (properties apparent in the direction of the applied load) whereas steel or aluminium is isotropic (uniform properties in all directions, independent of applied load). Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement. FRP composites are composed of:

- **Epoxy** - The primary functions of the resin are to transfer stress between the reinforcing fibers, act as a glue to hold the fibers together, and protect the fibers from mechanical and environmental damage. The most common resins used in the production of FRP grating are polyesters.
- **Reinforcements** - The primary function of fibers or reinforcements is to carry load along the length of the fiber to provide strength and stiffness in one direction. Reinforcements can be oriented to provide tailored properties in the direction of the loads imparted on the end product. The largest volume reinforcement is glass fiber.

- **Fillers** - Fillers are used to improve performance and reduce the cost of a composite by lowering compound cost of the significantly more expensive resin and imparting benefits as shrinkage control, surface smoothness, and crack resistance.
- **Additives** - Additives and modifier ingredients expand the usefulness of polymers, enhance their process ability or extend product durability.

An FRP is a specific type of two-component composite material consisting of high strength fibers embedded in a polymer matrix. The mechanical and physical properties are clearly controlled by their constituent properties and by the micro-structural configuration. While the fibers are mainly responsible for strength and stiffness properties, the polymeric matrix contributes to load transfer and provides environmental protection. In addition, fillers are used to reduce the cost and sometimes to improve performance, imparting benefits as shrinkage control, surface smoothness and crack resistance. Additives and modifiers ingredients can expand the usefulness of the polymeric matrix, enhance their processability or extend composite durability. The reinforcing of a low modulus polymeric matrix with high strength and modulus fibers utilizes the viscoelastic displacement of the matrix under stress to transfer the load to the fiber; this result in a high strength, high modulus composite material. The aim of the combination is to produce a two phase material in which the primary phase, that determines stiffness, is in the form of fibers and is well disperse and bonded and protected by a weak secondary phase, the polymeric matrix.

III. REINFORCING FIBERS

The fibers provide the strength and stiffness of an FRP. Because the fibers used in most structural FRP applications are continuous and are oriented in specified directions, FRPs are orthotropic, and they are much stronger and stiffer in the fiber direction(s).

According to Halliwell (2000), the functional requirements of fibers in a composite are:

High modulus of elasticity to give stiffness

- High ultimate strength
- Low variation of strength between individual fibers
- Stability during handling

Many different types of fibers are available for use, and all have their respective advantages and disadvantages. In civil engineering applications, the three most commonly used fiber types are glass, carbon (graphite), and to a lesser extent, aramid (Kevlar). The suitability of the various fibers for specific applications depends on a number of factors including the required strength, the stiffness, durability considerations, cost constraints, and the availability of component materials.

3.1 Glass fibers:

Glass fibers are commonly produced by a process called direct melt, wherein fibers with a diameter of 3 to 25 microns are formed by rapid and continuous drawing from a glass melt. Glass fibers are used for the majority of composite application because they are cheaper than the others. There are different forms known by names like E-glass (the most frequent used), S-glass (is a stringer and stiffer fiber with a greater corrosion resistance), R-glass (is a higher tensile strength and modulus and greater resistance to fatigue and aging) and AR-glass (an alkali-resistant glass used to reinforced concrete). The main characteristics of glass fibers are their high tensile strengths and moderate elastic modulus. Glass fibers are, also, excellent thermal and electrical insulators. Glass fibers are particularly sensitive to moisture, especially in the presence of salts and elevated alkalinity, and need to be well protected by the resin systems used in the FRP. Glass fibers are also susceptible to creep rupture and lose strength under sustained stresses.

3.2 Carbon fibers:

Carbon fibers are produced by a process called controlled pyrolysis, wherein one of three potential precursor fibers is subjected to a complex series of heat treatments (stabilization, carbonization, graphitization, and surface treatment) to produce carbon filaments with diameters in the range of 5-8 microns. The resulting fibers can have properties that vary widely, and so several classes of carbon fibers are available, differentiated based on their elastic moduli: Standard: 250-300 GPa, Intermediate: 300-350 GPa, High: 350-550GPa, Ultra-High: 550-1000 GPa. Although considerably more expensive than glass fibers, carbon fibers are beginning to see widespread use in structural engineering applications

1. OVERVIEW OF COMPOSITES DEVELOPMENT

•5000 a.C. – Use of straw in the reinforcement of mud bricks to reduce shrinkage cracks (Mesopotamia)
• 1940 – First structural applications of modern composites in naval and aerospace industries
• 1950 – Introduction of composites in automotive and oil industries
• 1960 – Development of advanced composites (defence industries) and first applications in construction
• 1970 – Effort to reduce manufacturing costs enables extension to new markets (e.g. sports goods)
• 1980 and 1990s: Technological development of manufacturing processes (e.g.pultrusion)

Increasing need to rehabilitate civil infrastructure (limited durability of traditional materials; increase of loads)
Requirement of increasing construction speed Increasing acceptance from construction industry

- ❖ High strength
- ❖ Low self-weight
- ❖ Durability

2. CONSTITUTION AND GENERAL PROPERTIES OF FRPS

Fibre Reinforced Polymer (FRP) materials - 2 phases:

1. Fibre reinforcement
- ❖ High resistance
- ❖ Brittle behavior
2. Polymeric matrix (resin + filler + additives)
- ❖ Very low resistance
- ❖ Load transfer and stress distribution between fibres
- ❖ Protection of fibres from environmental agents
- ❖ Keeping the fibres in position (and preventing their buckling when compressed)

CONSTITUTION AND GENERAL PROPERTIES OF FRPs

Properties of polymeric matrixes

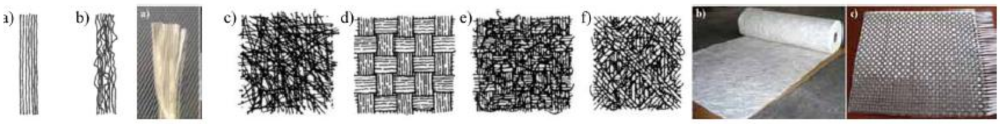
Polymer resins
- Thermoset (polyester, vinylester, epoxy)
- Thermoplastic (polyethylene, polypropylene)

Property	Polyester	Vinylester	Epoxy
Strength [MPa]	20 - 70	68 - 82	60 - 80
Elasticity modulus [GPa]	2 - 3	3.5	2 - 4
Strain at failure [%]	1 - 5	3 - 4	1 - 8
Density [g/cm^3]	1.2 - 1.3	1.12 - 1.16	1.2 - 1.3
Glass transition temperature [ºC]	70 - 120	102 - 150	100 - 270

Properties and forms of reinforcing fibres

Property	E - Glass	Carbon	Aramid
Strength [MPa]	2350 - 4600	2600 - 3600	2800 - 4100
Elasticity modulus [GPa]	73 - 88	200 - 400	70 - 190
Strain at failure [%]	2.5 - 4.5	0.6 - 1.5	2.0 - 4.0
Density [g/cm^3]	2.6	1.7 - 1.9	1.4

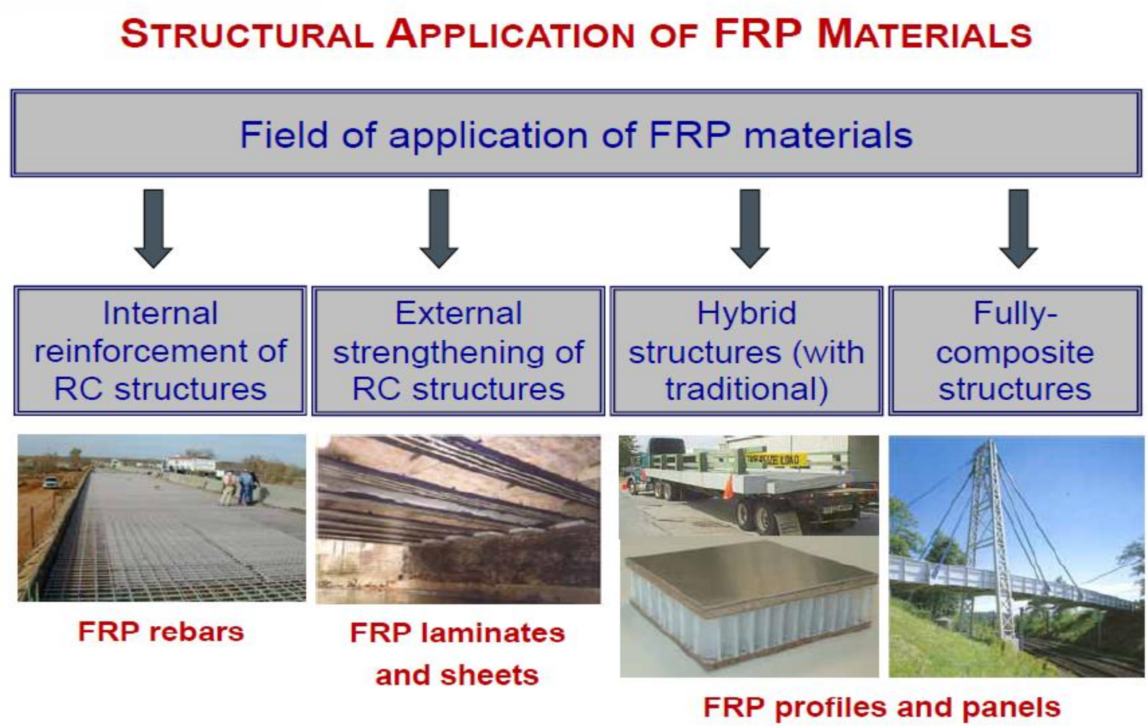
- Rovings (or tows) - bundles of continuous filaments
- Mats (*mats, veils, fabrics*) with short or continuous filaments, randomly oriented or oriented, woven or non-woven



Rovings   Mats, fabrics

The advantages of an FRP composites deck are lightweight, high strength and high performance, chemical and corrosion resistant, easy construction and handling, rapid project delivery, and in most cases, high quality shop fabrication. Its lightweight (88-171 kg/meter2 without a wearing surface overlay) reduces the overall superstructure weight and foundation requirement. In areas of high seismic zones, a reduced mass may be highly desirable. Although the composite materials are of high tensile strength, the current deck design is governed by stiffness requirements. The stiffness modulus of glass FRP composites is about one-fifth that of steel. Except for high or ultra high modulus carbon materials, the stiffness modulus of typical carbon fibers is slightly higher than structural steel.

There remain some challenges in the use of FRP composites for deck replacement. The design of an FRP deck system requires finite element analysis. Its lightweight in the superstructure can become aerodynamically unstable, especially for long span structures. As in any new innovation and being an anisotropic material, the composite components and system would require validation testing while building up a good database for each specific system. Depending on how a deck panel is fabricated, consistency and quality may vary. For field installation, connections and some other construction details would need to be developed, improved and tested. A well-designed and properly installed thin bonded overlay can improve traffic traction and extend the service life of the deck panels. Traffic railing connections would need to be designed and tested for crash worthiness. Nondestructive testing/evaluation devices should be incorporated into inaccessible parts of the deck panels to monitor short and long-term performance and to facilitate maintenance inspection. These disadvantages should not be viewed as hindrances. Rather, they should be welcomed as development opportunity for the engineering community and industry. As structural engineers learn more about the behavior of the composites, these problems will be resolved through proper applications, detailing and further research.



Advantages of Epoxy Resins over Other Polymers

The advantages of epoxy resins over other polymers as adhesive agents for civil engineering use can be summarised as follows:

• High surface activity and good wetting properties for a variety of substrates.

• May be formulated to have a long open time (the time between mixing and closing of the joint).

• High cured cohesive strength, so the joint failure may be dictated by the adherend strength, particularly with concrete substrates.

• May be toughened by the inclusion of a dispersed rubbery phase.

• Minimal shrinkage on curing, reducing bondline strain and allowing the bonding of large areas with only contact pressure.

• Low creep and superior strength retention under sustained load.
• Can be thixotropic for application to vertical surfaces.
• Able to accommodate irregular or thick bondlines.
• Formulation can be readily modified by blending with a variety of materials to achieve desirable properties.

3. ADVANTAGES AND LIMITATIONS OF FRP

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). However, there are some factors limiting its frequent use such as very high material cost, lack of design codes on FRP in many countries like India, unawareness of or reluctance to accept existing reports, guidelines and technical publications currently being used worldwide.

The following are major pros and cons of using Composites:

Advantages

- Corrosion proof.
- Higher UTS and young's modulus.
- Easy in transportation, can be installed easily.
- Light weight. Hence, very high strength to weight ratio.
- High fatigue resistance.
- Joints can be easily avoided as they are available in desired length.

Limitations

- Low ductility value and fickly plastic behaviour
- Susceptible to local unevenness.
- High cost.
- Low shear strength.

FRP's can be used in the concrete structures in following forms:

- Plates- at the face to improve the tension capacity.
- Laminates- below beams and slabs to improve load taking capacity.
- Bars- as reinforcements in beams and slabs replacing the steel bars
- Cables- can be used as tendons and post- tension members in suspension and bridge girders.
- Wraps- around concrete members i.e. columns, beams, slabs etc for confinement.

IV.CONCLUSION

• The development of Civil Engineering has been intimately connected to the innovation in structural materials.
• FRP composites are promising materials, presenting several advantages over traditional materials for both new construction and rehabilitation: strength, lightness, ease of application, durability under aggressive environments and low maintenance

• CFRP strengthening systems are an already well-established "standard" solution for RC strengthening, with several advantages over alternative techniques

• The limitations of other FRP materials are the motivation for seeking "material adapted" structural solutions, the main goal of the ongoing research projects at IST.

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