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Essential characteristics and applications of polymer composites in civil engineering

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Summary

Advances in construction materials enable civil and structural engineers to obtain important achievements in the functionality, safety and economy of construction. Polymeric composites are materials that contain a continuous polymeric matrix binding together and providing form to arrays of stronger and stiffer reinforcing constituents. Composite materials developed for structural applications provide attractive performance in other functional areas. These materials have higher specific strength and higher specific stiffness than traditional materials and can be tailored to meet specific demands, they exhibit good resistance to fatigue, have excellent corrosion resistance, dimensional stability and convenient electrical properties. Composite elements and structures can be fabricated efficiently and they are cost-competitive in life-cycle assessments. A realistic approach of the use of polymeric composites in civil engineering applications requires also a critical evaluation of the material drawbacks, therefore paper deals with some constrains that may prevent or limit the use these materials in construction. Some frequent applications of fibre reinforced polymeric composites are also presented and discussed.

KEY WORDS: fibre reinforced, polymeric composites, advantages, constraints, applications .

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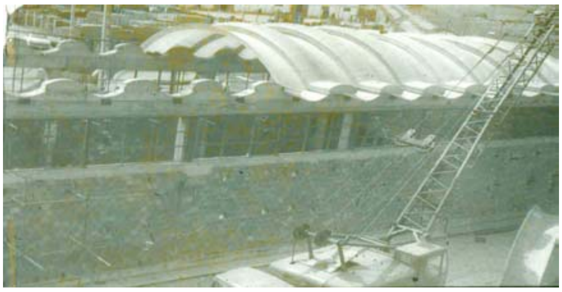
1. INTRODUCTION

Advances in construction materials enable civil and structural engineers to obtain important achievements in the functionality, safety and economy of construction. Polymeric composites are materials that contain a continuous polymeric matrix binding together and providing form to arrays of stronger and stiffer reinforcing constituents. Composite materials developed for structural applications provide attractive performance in other functional areas. These materials have higher specific strength and higher specific stiffness than traditional materials and can be tailored to meet specific demands, they exhibit good resistance to fatigue, have excellent corrosion resistance, dimensional stability and convenient electrical properties. Composite elements and structures can be fabricated efficiently and they are cost-competitive in life-cycle assessments. An efficient use of polymeric composites in civil engineering applications requires a good understanding of their properties, advantages and constraints. Some of these features relating to fibre reinforced polymeric (FRP) composites are briefly presented and analysed in this paper.

2. ADVANTAGES OF POLYMERIC COMPOSITES IN CONSTRUCTION INDUSTRY

Fibre reinforced polymeric composites became an important construction material in 1950s when glass-fibre plastics (GFRP) were put in broader use and provided significant improvements in structural response and corrosion response. Over the past four decades substantial investments from private and public funds were made toward research, development, testing, fabrication and demonstration projects, [5, 12], figure 1.

a.



b.

Figure 1. Structures made of glass-fibre reinforced polyesters: a. exhibition hall in Moscow, 1959; b. curved shell roof in Iasi, 1975

This was also a period of great innovation in manufacturing, assembly and repair method development. The construction industry has also become a major end user of FRP composites due to certain advantages that will be briefly discussed below. One of the most important features of FRP composites is that they usually exhibit the best qualities of their constituents and often some qualities that neither constituent possesses [7].

High specific strength is the most often mentioned advantage of FRP composites. This characteristic leads all composite light weight structures made of pultruded sections, figures 2 and 3, with improved performance and reduced energy consumption, both vitally important in the design of almost all engineering structures. The same advantage have enabled development of efficient strengthening solutions of civil engineering structures, figures 4, 5, 6 and 7, with little additional permanent loading, [13]. Table 1 gives typical densities of the most common fibre reinforced polymeric composites with common fibre volume fractions (V_f) used in civil engineering applications, [2].

Table 1. Typical densities of reinforcing bars for V_f=0.5 to 0.7 (kg/m^3)

FRP / Matrix	CFRP	AFRP	GFRP	Steel
Polyester	1430-1650	1310-1430	1750-2170	7900
Epoxy	1440-1670	1320-1450	1760-2180	
Vinyl ester	1440-1630	1300-1410	1730-2150	

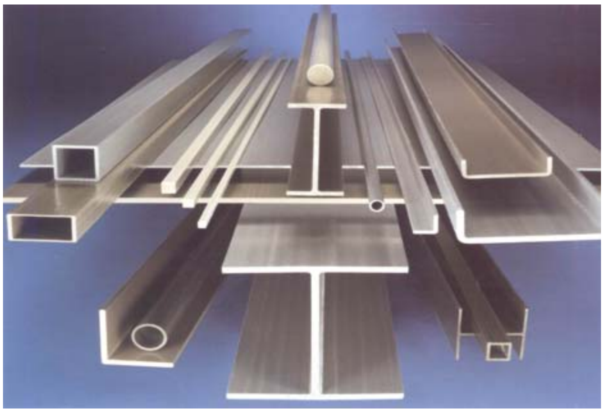


Figure 2. FRP Pultruded sections (www.strongwell.com)

Figure 3. Light weight bridge made of FRP sections (www.fiberline.com)

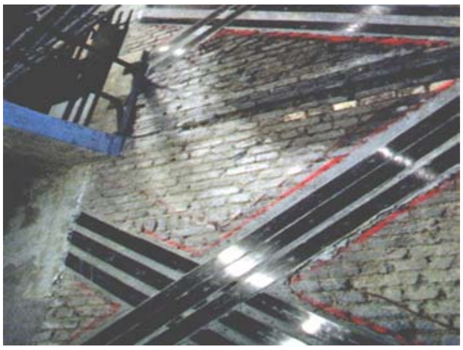


Figure 4. Strengthening of a masonry wall with FRP composites[www.sika.com]

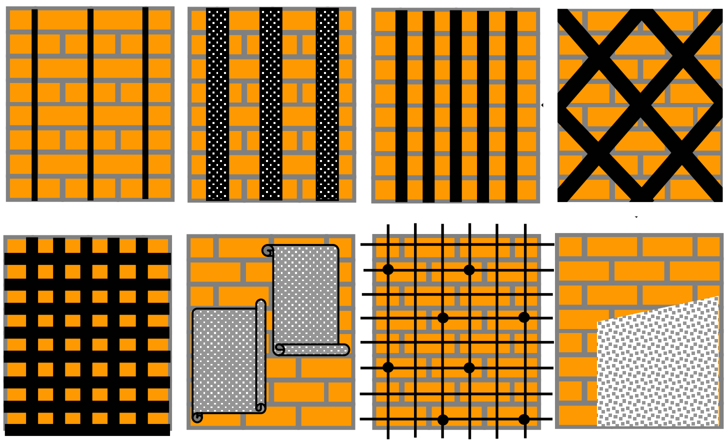


Figure 5. Masonry strengthening solutions with FRP composites[14]

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Figure 6. Strengthening of RC beams with prefabricated FRP plates and FRP wraps [CCC University of Sheffield]

Figure 7. Confinement of concrete columns with FRP composite jackets

[CCC University of Sheffield]

Tailored design enables FRP composites to be designed and manufactured to meet the specific requirements of a particular application. Available design variables include: the choice of constituents (fibre and polymeric matrix), the volume fractions of fibre and matrix, the manufacturing process, fibre and layer orientation

Figs. 8 and 9, number of layers in a specified direction, thickness of individual layers, type of layer (unidirectional or fabric) and layers stacking sequence. This vast array of design variables enables FRP composites to be designed for desired properties in specified directions without over-designing in other directions.

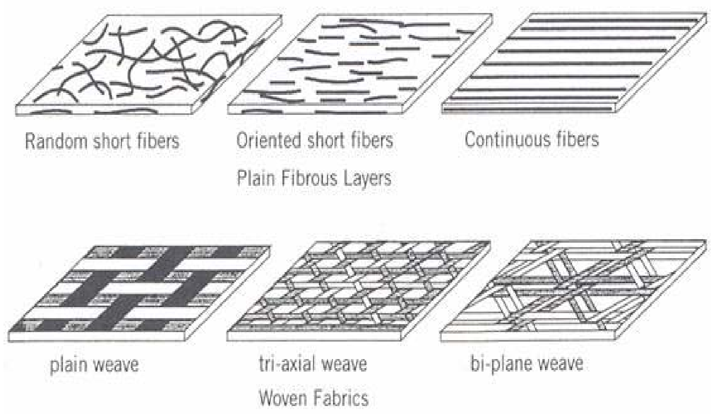

Figure 8. Types of fibre reinforcement for composites [15].

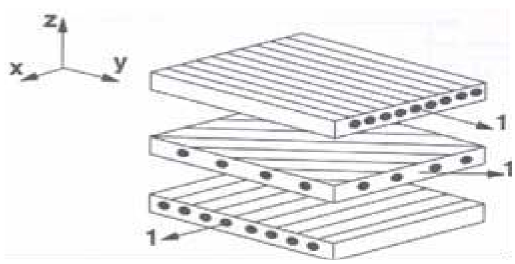

Figure 9. Lamina stacking [15].

Fatigue resistance of FRP composites is superior to that of most metals and metallic alloys. Their improved fatigue behaviour is explained by the complex deterioration mechanisms, Fig.10, under cyclic loading [16].

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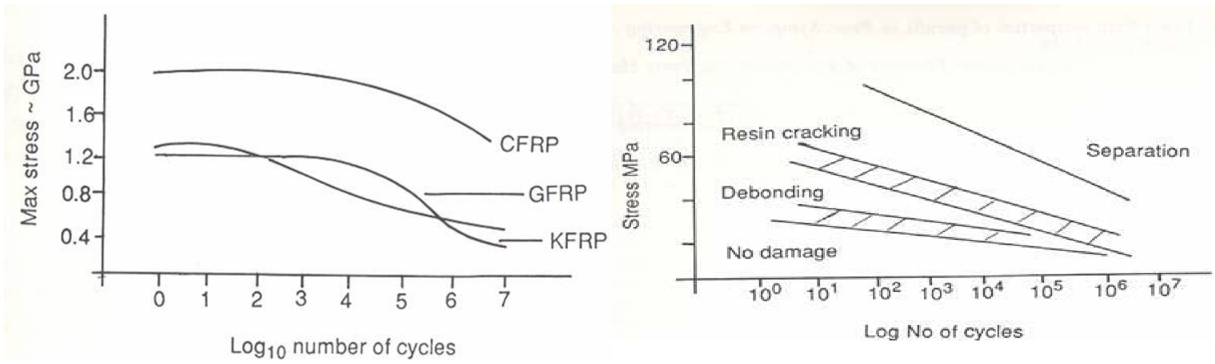

Figure 10. Fatigue resistance of FRP composites [16]:

a. Typical S-N curves for unidirectional composite

b. Damaging of GFRP under repeated loading

Dimensional stability is important in structural applications in which thermal stresses can be critical. Therefore controlling the values of thermal expansion coefficients (CTE) through proper design enable composites to match these characteristics so that resulting thermal stresses can be minimized. Typical values of CTEs for the most common FRPs used in civil engineering (AFRP = aramid fibre reinforced polymers; CFRP = carbon fibre reinforced polymers, GFRP = glass fibre reinforced polymers) are given in Table 2, [9].

Table 2. Typical coefficients of thermal expansion for FRP materials (V_f=0.5-0.7)

Direction	Coefficient of Thermal Expansion (x 10^{-6}/C)			
	Steel	GFRP	CFRP	AFRP
Longitudinal,α_L	11.7	6.0 to 10.0	-1,0 to 0	-2.0 to -6.0
Transverse,α_T	11.7	21.0 to 23.0	22.0 to 50.0	60.0 to 80.0

Corrosion resistance to various chemicals is one of the most significant advantages of FRP composites. Polymeric composites can often be made essentially maintenance free as compared to traditional engineering materials. This feature makes FRPs excellent choice for structures working in corrosive environments, [4, 6, 11], figure 11.

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Figure 11. Composite stairways in chemical processing environments (left) and operating platform in corrosive environment (right) [11].

Electrical non-conductivity of some FRPs, especially glass-fibre reinforced polyesters, is an essential feature that enables the replacement of steel and aluminum elements, [11], to reduce the possibility of electrocution, figure 12.

Figure 12. Electrically non-conducting elements [11].

Electromagnetic transparency is an essential characteristic for microwave related applications Electromagnetic non-interference is required for electronic testing facilities and for radar equipment shelters, figure 13.

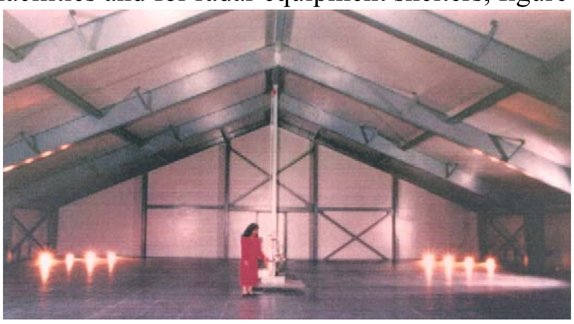

Figure 13. Test facilities for electronic components (left), [11], radom for radar equipment protection (right), [5].

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Formability enables FRP polymeric composites to be formed into complex, desired shapes. This makes possible efficient forms such as curved shells, folded plates, ribs and corrugations, variations in thickness and sandwiches, figure 14, enabling efficient stress distribution, appropriate stiffness and other functions.

Figure 14. Folded plate skylight (left), [12] and double curved sandwich structure, (right), [5].

Light transmission and translucency. Thin structural FRP composites can transmit a high percentage of incident light thus providing structure, enclosure and illumination, a combination unique among structural materials. These are essential features for skylights, atriums and waste water treatment facilities.

Cost-effective fabrication and repair. FRP composite structures can be fabricated efficiently through the use of automated methods, with little material waste. This is in contrast to the use of metals where it is often necessary to remove large portions of the material to arrive at final configuration. Composite structures can be manufactured for simple assembly, minimum painting requirements and moderate tooling cost. FRP composite parts can often be repaired and registered and restored on-site with minimum disruption of operations.

Overall cost considerations. A FRP composite element or structure can be cost competitive only if the total life time is assessed. On a per kilogram basis FRP composites are more expensive than traditional construction materials. For a realistic cost comparison other factors should be included [7].

less material is required because of higher specific strength;

many times fabrication costs are lower;

transportation and erection costs are generally lower for structures made of FRP composites;

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in most cases life of the composite structures will be longer than that made of traditional materials and will require less maintenance during its life span.

disadvantages OF FRP COMPOSITES IN construction industry

The use of FRP polymeric composites in construction may be sometimes obstructed due to some particularities of their behaviour, properties or due to misconceptions about the material.

Lack of ductility. In many cases the yield and ultimate strengths are almost the same and they can be considered to be identical. Due to the absence of plastic flow at yield, figure 15, FRP composites are incapable of relieving stress concentrations, [3].

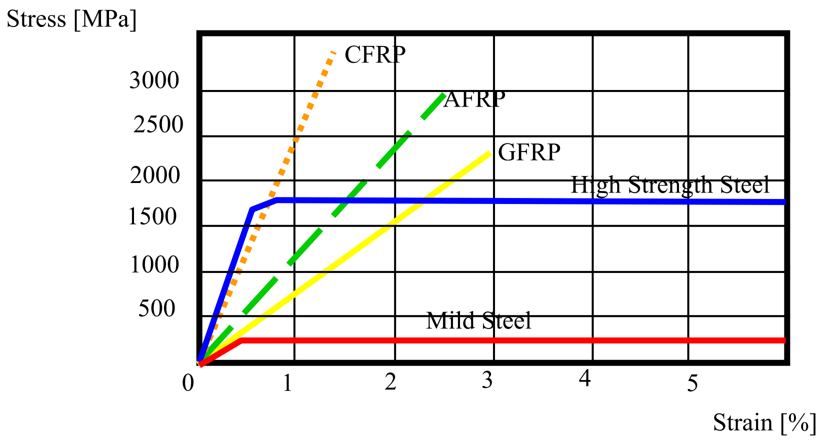

Figure 15. Stress-strain curves of FRP and steel

Different values of strength and modulus in tension and compression. Experimental work [8] has proved that compressive strengths of FRPs are lower than the tensile strengths. Compressive strengths are higher for bars with higher tensile strengths, except for AFRP bars where fibres have a nonlinear behaviour in compression even at low levels of stress. The compressive modulus of elasticity of FRP reinforcing bars is also smaller than its tensile modulus of elasticity. The compressive modulus of elasticity is about 80 % for GFRP, 85 % for CFRP and 100 % of the same products made of AFRP, [1].

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FRP composites exhibit anisotropic behaviour. Fibre reinforced polymeric composites are orthotropic when are reinforced with unidirectional fibres, woven roving and cloth. Special attention should be given to transverse properties which are mainly determined by the polymeric matrices.

The mechanical properties can be affected by the rate of straining, temperature and duration of loading. In civil engineering practice it is difficult to define the rate at which loading is imposed on the structure. The effects of time and high temperature, figure 16, on the behaviour of polymeric matrix are similar, in the sense that the creep strain can be accumulated over time. High fibre volume fractions reduce these effects and decrease the creep rate. Long term high temperature exposure may cause degradation due to thermal effects. In FRP composites, low temperatures lead to matrix shrinkage and because of the relatively stiffer fibres residual stresses may arise. Except for very cold environments the induced stresses are insignificant.

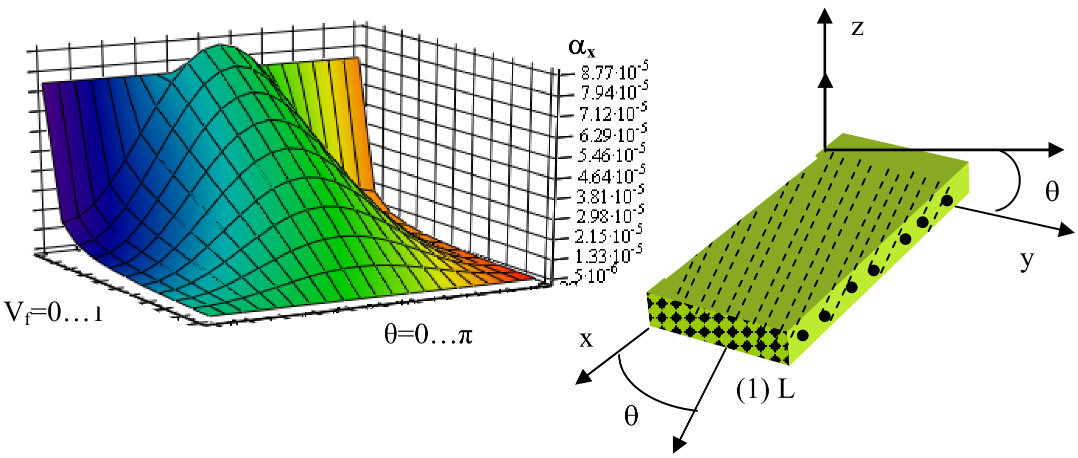

Figure 16. Variation of coefficients of thermal expansion with fibre orientation and fibre volume fraction [12]

The properties of FRP composites can be affected by environmental conditions. Some polymeric resins although may be attacked by chemical solvents or alkalis. In particular bare glass fibres can be degraded by the alkaline solutions. However suitable polymeric resins can protect the fibre and slow the diffusion process. In particular vinyl esters provide a protective barrier and FRP composites can perform well in alkaline environments [10].

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The fire effects. Fire may ignite the composite materials with organic matrices and the results of this ignition are the spread of flame on the composite surface, release of heat and generation of smoke (potentially toxic). When the polymeric resin in the outermost layer of a FRP element burns, heat-induced gasification occurs. This has an insulating effect, slowing the heat penetration in the depth of composite. The first effect of fire is to heat up the composite surface. Over the core of the composite element heated at temperatures beyond glass transition temperature, the elastic modulus of composite decreases. This loss in modulus is reversible below the temperature of chemical degradation.

Effects of UV radiation. Polymeric resins are significantly affected by action of UV radiation. A long exposure to UV radiation may determine the matrix to harden and change in colour. These effects are, however, felt only on a thin surface layer and research work carried out on this topic showed that the UV effects on structural properties is minimal. Application of UV resistant coatings to the surface of FRP composite elements has a good protective influence.

3. CONCLUSIONS

The use of FRP in civil engineering applications enables engineers to obtain significant achievements in the functionality, safety and economy of construction. These materials have high ratio of strength ro density, can be tailored to posses certain mechanical characteristics, have excellent corrosion behaviour, convenient electrical, magnetic and thermal properties. On the other hand FRP composites are brittle, exhibit anisotropic behaviour and their mechanical properties may be affected by the rate of loading, temperature and environmental conditions. Therefore an efficient use of polymeric composites in construction requires a careful evaluation of all aspects involved.

References

1. ACI 440.1R.: "Guide for the Design and Construction of Concrete Reinforced with FRP Bars", Reported by ACI Committee 440, 41pp, American Concrete Institute, 2001.
2. ACI 440.2R. :"Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures". Reported by ACI Committee 440,45pp. American Concrete Institute, 2002
3. Benjamin, B.S.: "Structural Design with Plastics" 2nd ed. Van Nostrand, Reinhold, New York, 1981.
4. Creative Pultrusions "Pultex design manual", <www.creativepultrusions.com>, 2001.
5. Dietz, A. G. H., "Plastics for Architects and Builders", The MIT Press, Massachusetts, 1969.
6. Fiberline: "Fiberline Design Manual".<www.fiberline.de.> 1995
7. Herakovich, C. T.:" Mechanics of Fibrous Composites". John Wiley & Sons, New York, 1998

ISSN 1582-3024

8. Mallick, P. K.: "Fiber Reinforced Composites, Materials, Manufacturing and Design" Marcel Dekker Inc., New York, 1988
9. Rizkalla, S., and Mufti, A.: "Reinforcing Concrete with Fibre Reinforced Polymers*",* ISIS Design Manual No 3, ISIS Canada, Manitoba, 2001
10. Sheard, P.:"Composites in Construction. Frequently Encountered Misconceptions" Lecture notes. University of Sheffield, 2003.
11. Strongwell.:"EXTREN fibreglass structural shapes"-Design manual, Bristol, Va., <www.strongwell.com>, 1999
12. Taranu, N., Isopescu, D., "Structures Made of Composite Materials", Vesper, Iasi, 1996.
13. Taljsten, B., 2003, FRP Strengthening of Existing Structures. Design Guideline. Lulea University Printing Office, Lulea.
14. Oprisan G., Taranu N., Entuc I., "Strengthening of unreinforced masonry walls with composite materials"**,** Bul. IP Iasi, Fasc.1-2, Constr. si Arhitectura, 2004, 11pp.
15. Gurdal Z., Haftka R., Hajela P., "Design and oprtimization of laminated composite materials", John Wiley & Sons, New York, 1999.
16. Hollaway L.- Polymer composites for civil and structural engineering. Chapman and Hall, Glasgow, 1993.

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