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APPLICATION OF MODERN POLYMERIC COMPOSITE MATERIALS IN INDUSTRIAL CONSTRUCTION

BY

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Abstract. The large variety of modern composite materials and products existing nowadays in the construction market provides multiple and convenient possibilities to use them in both structural and nonstructural industrial construction elements. The main advantages of modern composite materials such as: corrosion resistance, high strength and modulus values compared to their density, 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. The high potential of the applicability of polymeric composites in new industrial construction correlated with fabrication procedures as well as the use of composites in modern strengthening solutions are presented in the paper.

Key words: fibre reinforced polymer (FRP); FRP elements; pultruded shapes; hybrid elements; strengthening solutions.

1. Introduction

Composites are materials consisting of two or more chemically distinct constituents on a macro-scale, having a distinct interface separating them, and with properties which cannot be obtained by any constituent working individually [1].

Composite materials are divided in five principal types: polymer matrix composite (PMC), metal matrix composite (MMC), ceramic matrix composites (CMC), Carbon–Carbon (CC) and hybrid composites (HC). Polymer matrix composites and especially fibre reinforced polymer (FRP) are widely utilized in construction applications, including industrial and agricultural buildings.

The use of FRP composites in agricultural and industrial buildings for structural and nonstructural elements is motivated by their main advantages among which can be mentioned: high specific strength, tailored design through controlled anisotropy, formability, fatigue resistance, controlled dimensional stability, corrosion resistance to various chemicals, wear resistance, convenient thermal and acoustical characteristics, light transmission and translucency, electromagnetic transparency, electrical non-conductivity, etc. [2].

The utilisation 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 and its potential: lack of ductility (Fig. 1); different values of strength and modulus in tension and compression; the mechanical properties can be affected by the rate of straining, temperature and duration of loading; the properties of FRP composites can be affected by some environmental conditions; the fire may negatively influence the matrix properties; and the UV radiation may slightly deteriorate the superficial layers of the FRP composites.

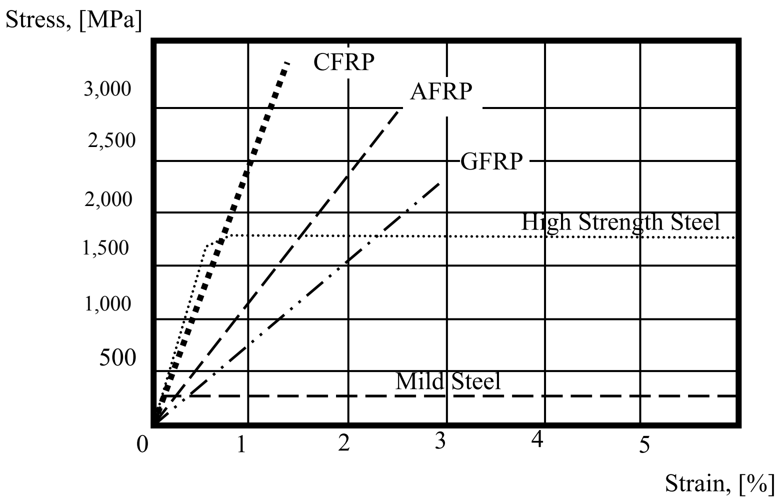


Fig. 1 – Comparative stress–strain curves of some FRP composites and steel.

An 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 [3]: 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; 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.

2. Applications of FRP Composites in Industrial Construction

In the past three decades FRP composites have won an increasing mass fraction of military and civil applications. Significant investments from private and public funds were made toward research, development, testing, fabrication and demonstration projects. Confidence in using composite materials increased dramatically. 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. Nowadays the construction industry utilizes FRP composites based on glass, carbon and aramid fibres embedded in matrices made of polyester, epoxy and vynilester resins [4]. Recently basalt fibres have been introduced especially in application requiring high temperature exploitation [5].

The range of properties of FRP composites as well as the formability of FRP composite elements provides a large variety of load bearing and non structural applications for civil engineering area. Linear elements, plate and shells elements and folded structures can be easily fabricated and assembled in different types of buildings or structures [2].

Fig. 2 – FRP Pultruded sections and chemical platform with these products [6].

a *b*

Fig. 3 – FRP composite tanks: *a* – horizontal tanks [7]; *b* – vertical tanks [8].

Fabrication procedures have been specially developed for FRP composite elements and structures; consequently they have penetrated almost any domain of industrial and agricultural buildings. Mass production or niche fabrication are currently providing a variety of structural shapes or bars fabricated by pultrusion and platforms for chemical industry are especially made of these profiles (Fig. 2). Transport and storage construction elements such as pipes and tanks, are produced using filament winding (Fig. 3).

Large scale elements with complicated shapes, covering parts for roofs (Figs. 4 and 5), are made using hand lay-up and/or spray-up.

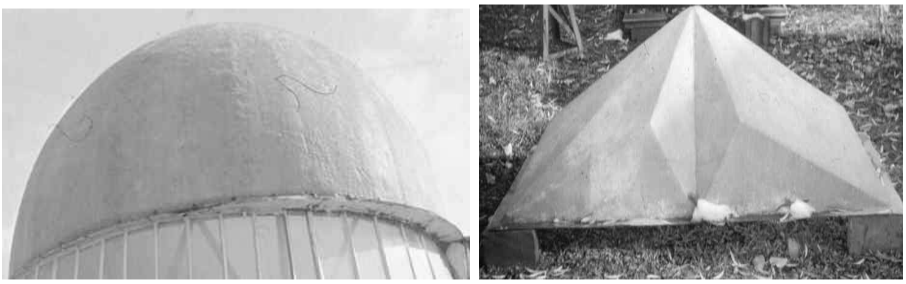


Fig. 4 – Large scale GFR polyester dome and skylight [2].

Fig. 5 – Folded skylight on an industrial workshop; Double curved shells for an industrial roof [9].

An application of increasing importance is the use of composites in wind turbine blades (Fig.6 *a*). Blades of unusual lengths (up to 125 m) made of a sandwich construction consisting of FRP facings and light weight foam cores have become familiar in many regions where wind speeds are high and the wind blows almost continuously. These wind turbines provide a valuable source of clean and renewable energy.

The offshore platforms have become a new important sector of use for advanced polymer composites. Particular examples for the application of FRP composites for the offshore construction include: firewater piping, sea water piping, grating, storage vessels, fire and blast walls (Fig. 6 *b*). Recent developments of fibre glass pipes have overcome one of their major drawbacks, namely leakage [10]. Carbon fibre reinforced polymers (CFRP) composites are utilized not only in underwater piping but also in structural parts of the platform. On the offshore platform the initial fears of fire hazard decreased after the research

a

b

Fig. 6 – *a* – Blades made of glass fibre reinforced polymer (GFRP) [4];
b – FRP composite components for an offshore platform [6].

work showed that composite laminates thicker than 8 mm perform better than steel in a major fire. The stairways and walkways are also made of composites for weight saving and corrosion resistance. Even the cables and ropes made of steel are now being replaced by similar items made of aramid or high modulus polyethylene fibres [4].

3. Application of FRP Composite Systems in Strengthening of Industrial Constructions

Strengthening rehabilitation of deteriorated and damaged industrial constructions has become one of the major issues for civil and industrial engineers all over the world. The main reasons for structural rehabilitation of the structural elements include: changes in the use of structure and degradation of the structure [11]. Changes in the use of structure include increased live load or dead load, change in the load path, new loading requirements and modernization of design practice. Degradation of the structure comprises: corrosion as a mechanism of structural degradation, fatigue of construction materials, hazard events, construction errors due to poor construction workmanship or the use of inferior materials.

FRP composites are recommended for structural rehabilitation solutions because the materials utilized are light-weight, corrosion resistant and suitable to tailored design. In addition, the FRP composite products are easily attached to surfaces of elements made of traditional material, require less labour force and do not modify the dynamic and the seismic characteristics of the load bearing elements.

A few case studies on the FRP composite application in structural rehabilitation works are presented in the following.

A comprehensive theoretical and experimental project has been carried out by the authors at the Faculty of Civil Engineering and Building Services, "Gh. Asachi" Technical University of Iaşi on the strengthening possibilities with advanced polymeric composites of a complete industrial hall. All structural members and cladding element have been analysed and the proposed solutions are illustrated in Fig. 7 [12], [13].

Industrial chimneys are special industrial structures exploited under severe wind, seismic and temperature difference conditions.

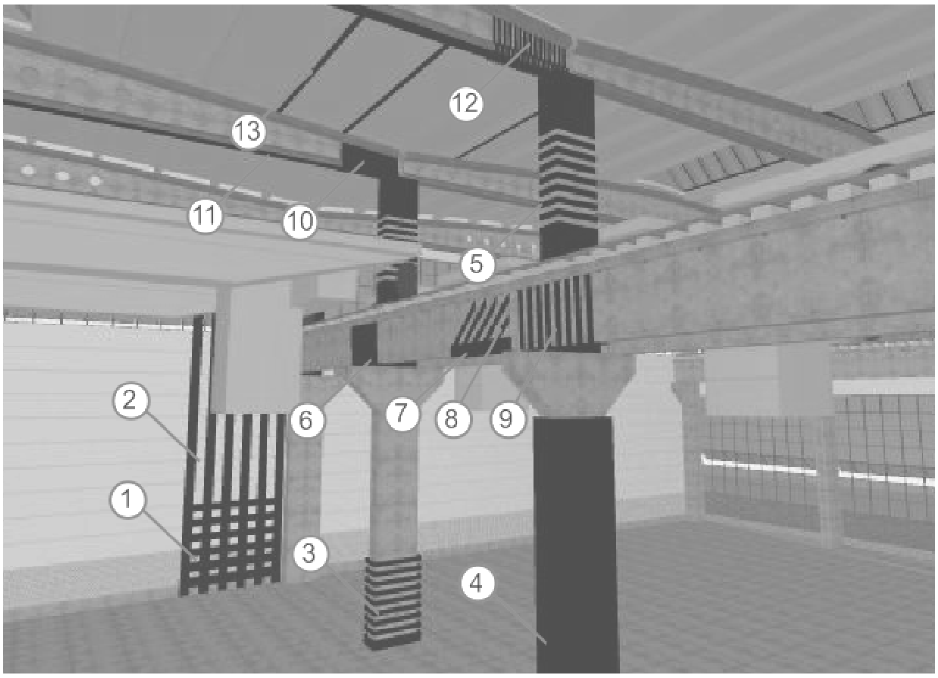
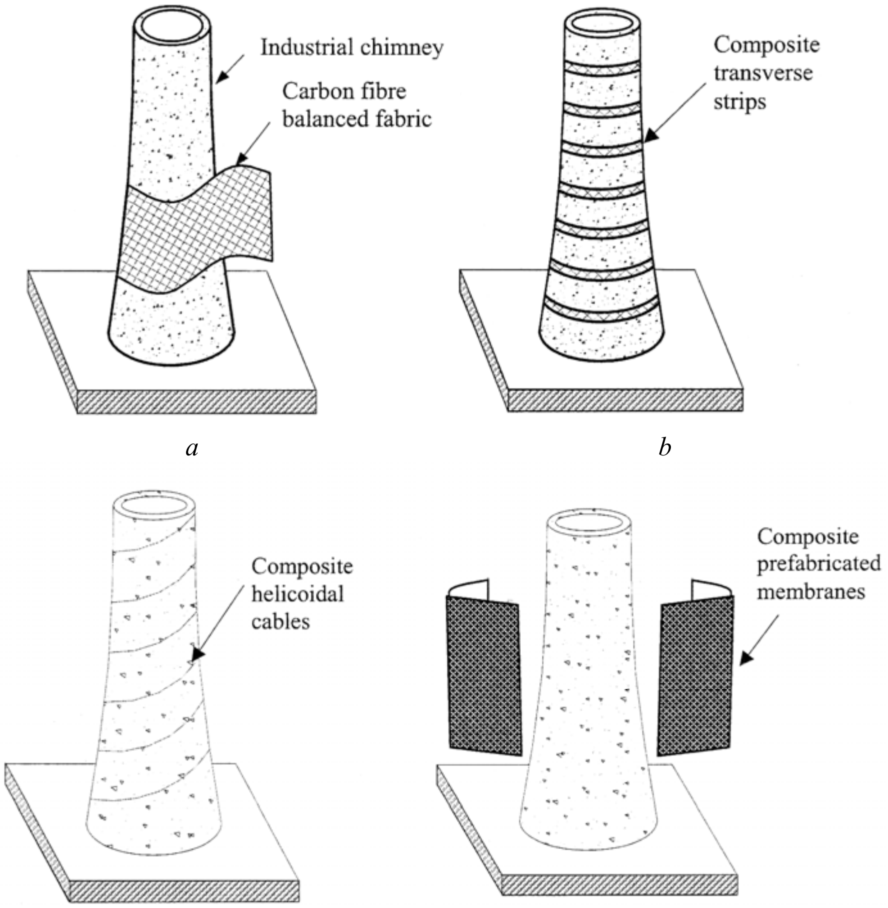


Fig. 7 – Strengthening solutions using FRP based solutions for an industrial hall: *a* – wall strengthening with bidirectional strips (*1*) and unidirectional strips (*2*); *b* – column strengthening using discrete strips (*3*), continuous wrapping (*4*) and combined discrete and continuous wrapping (*5*); *c* – discrete bending strengthening solutions for reinforced concrete (RC) girders and continuous membranes (*6*); *d* – shear strengthening solutions for RC girders using bottom flange clamping of inclined strips for runway girders (*7*) and (*8*) and U-shaped bands (*9*); *e* – strengthening solution for main transverse girders including end textile clamping (*10*), plate bonding (*11*) and discrete clamping made of composite strips (*12*); *f* – plate bonded ribs for roof elements (*13*).

Chimneys made of brick and reinforced concrete have been structurally assessed and strengthening solutions have been proposed.



a *b*

c *d*

Fig. 8 – Composite based strengthening solutions for industrial chimneys: *a* – wrapping with carbon fibre balanced fabric; *b* – confinement with composite hoop strips; *c* – helicoidal spiral made of composite cable; *d* – prefabricated composite membranes [14].

A similar application has been developed for a masonry chimney in a beer factory [15]. In this case the designer has suggested the use of carbon fibre reinforced textile composites to strengthen the chimney structure.

Silos constructions are often utilized in industrial areas, been exploited under corrosive atmosphere conditions the construction material is degraded and strengthening solutions are needed. A modern approach utilizes near surface mounted (NSM) strips/bars made of advanced composite materials [16]. These reinforcing elements are mounted in near surface slots, cut in the external layer of the original structure (Fig. 9 *a*). Alternatively composite hoop strips may be utilized to strengthen the shell of the construction (Fig. 9 *b*).

a *b*

Fig. 9 – Strengthening solutions for RC silos: *a* – near surface mounted composite strips; *b* – carbon fibre composite hoop strips.

A synthesis of potential application of advanced polymeric composites is presented in Table 1.

Table 1

The Main Areas of Composite Materials Usage in the Industrial Construction Domain

Domain / Fabrication procedure	Industrial buildings
FRP structural members as pultruded profiles	Structural systems: FRP frames, FRP grids, internal reinforcements for concrete and timber elements, FRP prestressed concrete elements; strengthening of load bearing elements made of traditional materials (concrete, masonry, timber, metallic elements)
FRP nonstructural members as pultruded profiles	Industrial doors and windows, FRP ventilation systems, etc.
Filament winding	Tanks, pipes, tube formwork for round concrete column casting, etc.
Hand lay-up; spray-up	Complex shapes for roofs, repair of existing components, industrial flooring
Continuous laminating	Roof and walls (building envelope)
Injection moulding	Moulded grating and stair tread with slip resistance surface, corrosion and chemical resistance and fire retardant used for offshore platform structures and chemical environments
Spray-up technique	Industrial buildings floors (wearing layer), using short fibres such as carbon and glass for structural strengthening works

4. 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 to 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.

In the area of industrial construction, where the working conditions are influenced by the aggressivily of environmental atmosphere, a particular importance is dedicated to structural rehabilitation of the load bearing components. The advanced polymeric composites offer convenient strengthening solutions for linear, folded, plate and curved construction elements.

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UTILIZAREA MATERIALELOR COMPOZITE MODERNE LA CONSTRUCŢIILE INDUSTRIALE

(Rezumat)

Varietatea materialelor şi produselor din materialele compozite moderne existente în prezent pe piaţa construcţiilor oferă posibilităţi multiple şi convenabile atât pentru realizarea elementelor de construcţii portante cât şi a elementelor nestructurale în construcţii industriale. Principalele avantaje ale materialelor compozite moderne se referă la: rezistenţă la coroziune, caracteristici mecanice cu valori ridicate, greutate specifică redusă, neutralitate magnetică, deformabilitate acceptabilă, proiectare dirijată, şi formabilitate excelentă. Aceste avantaje permit realizarea unei game largi de produse pentru construcţiile industriale şi proiectarea unor multiple soluţii pentru reabilitarea structurală a construcţiilor existente.

Se analizează potenţialul de aplicare a compozitelor polimerice în construcţii industriale noi, corelat cu procedeele de fabricare şi posibilitatea utilizării compozitelor polimerice la soluţiile moderne de consolidare.