Використання волоконно-армованих полімерів (FRP) в будівництві: обґрунтована альтернатива традиційним будматеріалам

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Будівельна промисловість відповідає близько за 40% загального виділення вуглекислого газу в атмосферу (джерело: Рада зеленого будівництва 2009). Усі процеси і продукти, пов'язані з будівництвом спричиняють виділення до атмосфери величезних кількостей CO_2, перевищуючи інші сектори, наприклад, промисловий чи транспортний (Рис. 1). Причини цього тривожного стану речей пов'язані зі складністю життєвого циклу будівельної продукції і величезною кількістю енергії, яка необхідна на різних стадіях життя будівлі: від виробництва будівельних матеріалів, через їх транспорт і монтаж на будівельному об'єкті, використання та ремонт, до демонтажу й можливої переробки будівельних складових у кінці будівельного циклу.

Для того, щоб задумати будівництво, яке матиме як найменший можливий вплив на навколишнє середовище головними чинниками є відповідальне управління процесом будівництва і належний вибір будматеріалів. Високі фізичні і механічні якості є дуже істотними для оптимізації, а разом з тим для зменшення кількості використаних матеріалів і засобів. Волоконно-армовані композити (FRP) гарантують значне зниження виділення шкідливих речовин протягом повного життєвого циклу будівлі, особливо, через специфічні характеристики матеріалу для виготовлення легких, тривалих і нескладних у монтажу споруд.

Серед різних виробничих технік, здається, що пултрузія є таким виробничим процесом, який найбільш суттєво скорочує енергоспоживання і виділення вуглекислого газу протягом стадії виробництва, зменшуючи одночасно вплив на навколишнє середовище. Навіть фізичне і структурне виконання будівель побудованих повністю з FRP може порівнюватися з виконанням традиційних будинків, тому може розглядатися як обґрунтована альтернатива для майбутнього розвитку будівництва.

Переклад виконано в Агенції перекладів PIO
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Use of fiber reinforced polymers (FRP) in construction: a sustainable alternative to traditional building materials

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The construction industry is responsible for about 40% of total emissions of carbon dioxide in the atmosphere (source Green Building Council 2009). All the processes and products related to the building construction cause the emission in atmosfere of huge quantities of CO2; higher than those produced by other impactful sectors as the industrial and transport fields (Fig. 1). The reasons for this alarming data are related to the complexity of the life-cycle of building products and to the huge quantity of energy that is associated to the different stages of a building's life: from the production of construction materials, through transport and assemblage on the construction site, use and maintenance, to disassemblage and eventual recycling of building components at the end of the building's life- cycle.

A responsible management of the construction process and a proper selection of building materials are therefore essential to conceive a building that has the least possible environmental impact. High physical and mechanical performance are essential to optimize, and thus reduce, the amount of materials and resources used. The fiber-reinforced composites (FRP) seem to guarantee a significant reduction in terms of emissions during the entire building life-cycle, especially due to the specific characteristics of the material which allows the construction of lightweight buildings, easily assembled and with a remarkable durability.

Keywords – fiber reinforced composites (FRP), pultruded fiber-glass, new construction materials, building construction, Life Cycle Assessment (LCA).

I. Introduction

The present article aims to provide a general overview related to the benefits of the widespread use of fiber reinforced composites - FRP - in building construction practice, as a substitute of traditional building materials such as steel, concrete and brick.

The use of innovative materials, with high levels of performance, both from the physical and the structural point of view ensures the reduction and optimization of components used in building construction. But not only; the use of high performance building materials could reduce the energy consumption during the life of the building, for example in relation to the energy consumption for cooling and heating the building. The impact of a material or component from the environmental point of view, in fact, is not tied exclusively to the production phase but it is distributed over all phases of its life cycle - from cradle to grave - and then to all those consecutive steps ranging from the production, assembly, use and disposal.

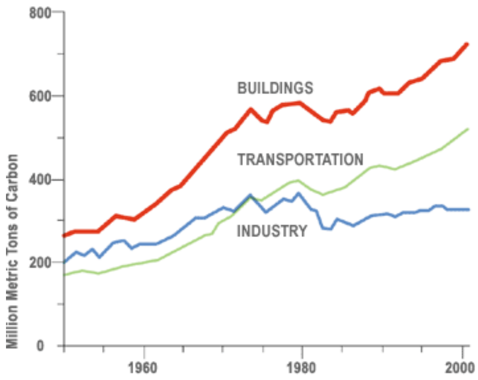
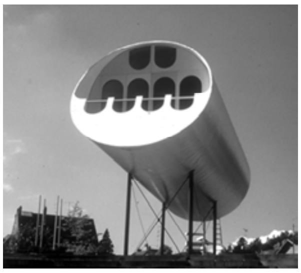


Fig. 1. Total CO_2 emissions in atmosfere due to the building, trasportation and industry sectors. Data provided by the Green Building Council, 2009

II. Diffusion of FRP in building construction practice

The history of composite materials is relatively recent. They were used in the nautical and aerospace fields from the early thirties of the 20th century and were transferred to the construction industry only since the mid-50s of the same century. This process of technology transfer was carried out thanks to the special properties of the material that proved to be immediately suitable for use as building cladding and structure. The characteristics of resistance to aging and highly corrosive environments, are now a distinctive feature of FRP materials compared to traditional building envelope components. After a first utilization in "experimental" buildings, which lasted until the second half of the 70s, the construction sector gradually lost interest on the fiber reinforced composite materials, until their rediscovery in early 90s. During this period, in fact, the production technologies allowed to achieve excellent levels of reliability and homogeneity for the material's performance and some industrial processes, in particular the pultrusion process, provided exceptional building components, very similar to traditional ones.



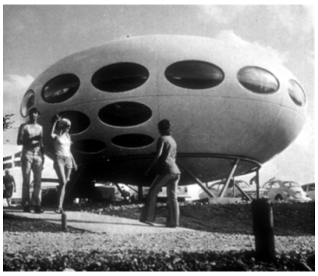


Fig. 2. Two examples of early FRP buildings. They were mainly experimental and were disassembled at the end of the 1970

The advantages related to the use of pultruded fiber-reinforced materials in the building practice are numerous, both from the structural performance point of view - in form of pultruded profiles – and from the envelope performance point of view - in form of pultruded panels. These advantages are evident due to the increase in physical and mechanical performance of the building and because of the better qualities of environmental sustainability during the manufacturing of the building. The duration of building performance over time is proved and maintenance of building components is often absent. This mantains the energy consumption along the life of the building on very low values, certainly lower than those of traditional buildings.

III. Field of application of FRP in building construction practice

Fiber-reinforced composite materials consist essentially of two basic materials: fiber and resin. The fibers may be artificial, such as glass, carbon or kevlar, or natural, such as hemp, flax or coconut. The matrices (or resins) are essentially of two types, thermoplastics and thermosets, and differ both for the materic properties and for the crosslinking process. Fillers are usually added to fibers and resins in order to reduce the amount of resin used and therefore the cost of the final product. Additives serve to enhance specific material properties, such as resistance to fire, or they can be used to achieve particular aesthetic properties and surface finish.

The applications of composite materials in construction can be divided into four broad categories based on different type of fibers design (uniaxial, biaxial, triaxial, or quadriaxial) but also for the different application techniques and processes used during the industrial production.

Following are listed the main areas of application of FRP materials in construction practice.

- Consolidation and restoration of walls and damaged structures. The fibers, in this case, are woven in two or three dimensions and are placed directly on the structures that need to be consolidated. The polymer matrix is applied manually on the textile thus allowing, on the one hand, the hardening of the tissue and, secondly, the bonding with the underlying structural element. Many interventions involve the vaults of historic buildings or concrete structures, damaged by seismic events, that can not be weighed down by new structures and require local actions able to restore the full static functionality of the elements. Advantages of this application are the lightness of the intervention and the short working time.

- A second application is the use of pultruded rods, particularly glass fiber, as a reinforcement for the concrete. The FRP material replaces the function of the steel. The benefits in this case are no longer related to the weight of the material but rather on the ability to resist to corrosion, which usually involves the reinforcement steel. It seems to be very interesting and advantageous to use these structures to built road bridges in cold climates, where frequent freeze-thaw phenomena and salt attack are consistent and can severely damage infrastructures.

- A third application concerns only the fibers. In particular, the glass fibers are reduced to a few centimeters in length and used within the concrete as fillers. The result is a material also known as Glass Fiber Concrete that has high resistance, due to homogeneous distribution of fibers within the concrete, and reduced cracking phenomena.

- The last application, certainly the most interesting for its impact on the construction industry, allows to fully exploit the properties of the composite material. Through the industrial process of pultrusion (a term that derives from the combination of PULL and EXTRUSION) it is possible to obtain structural elements, fully made by fiber glass, with open or closed section and with variable length. The open section profiles are usually used with pure structural function, in form of beams and columns and can reach widths of 100 cm and lengths of 10-15 meters. The profiles with closed sections, instead, can be joined together to form panels that, filled with suitable insulating materials, allow to reach high values of thermal resistance and acoustic impedance.

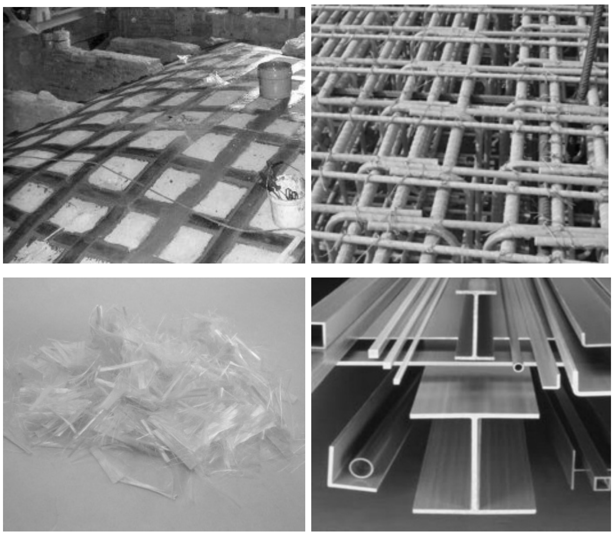


Fig. 3. Different applications of FRP materials. Four cases are present: the restoration of historic buildings, the use in bars to produce high-strength reinforced concrete, short fibers to produce Fiber Reinforced Concrete and, bottom-right, pultruded profiles for the construction of all-FRP structures

IV. Physical and structural properties of Glass Fiber Reinforced Polymers

The properties of composite materials derive from the physico-chemical interaction between fibers and polymer matrix, that varies depending on the type of fiber in use. In almost all the applications carbon fibers and glass fibers are used. In normal structural applications the utilization of E-glass pultruded fibers is the predominant portion of the market, thanks mainly to the cost of the fibers. The use of carbon and kevlar is reduced mainly to restoration of buildings. For this reason, with specific reference to the fiberglass pultruded profiles, it is possible to make a generalization about the main features of the material.

- Lightweight. The density of the material varies, depending on the amount of tissue, the so-called volume fraction (V_f), from 1800 to 2000 kg/m^3. Generally, the Vf is contained in a range between 50% and 60% that is able to ensure adequate formation of bonds between fiber and matrix in the material. An excessive fiber content leads to a high fragility of the material and an increase of the phenomena of debonding between fiber and matrix that are the basis of brittle mechanisms of rupture.

- High specific strength. It is theoretically possible to build large structures with extreme height and length, because of the very low ratio between the specific weight of the material and its resistance.

- Low thermal conductivity, depending on the type of resin used, it varies between 0.05 and 0.4 W/mK.

- Reduction of noise, due to the high dissipation of the vibrations produced by the impact of the sound wave on the material.

- Depending on the type of resin it is possible to obtain a good degree of translucency of the material that enhances the passage of light radiation.

- Resistant to moisture and liquids, depending on the particular type of resin used and the additives that are used with the matrix.

- High resistance to acid and saline environments, is very common to use pultruded fiberglass components for the construction of road bridge decks, especially in those climates where it is expected the use of salt on the roads during the cold season.

- Good resistance to fire, through the use of additives in the resin was found a good resistance to high temperatures. Several mechanisms for active protection of composite materials can be implemented in order to avoid to exceed the glass transition temperature (T_g) of the resin. It could cause a total loss of cohesion between fiber and matrix and then a collapse of the structural performance.

It is clear that the material is suitable for building applications and, in particular due to its high specific strength and low thermal conductivity values its use seems particularly suitable for the building envelope.

V. All-FRP buildings: structural and cladding pultruded elements for high performance buildings

As noted in the introductory paragraph (cfr. §1) the first "all-FRP" buildings, dating back to the '50s, have not the expected success and if, on one hand, they proved to be suitable for testing the material, on the other hand they failed the social acceptance that was too tied to traditional construction materials. Moreover, the scarcity of studies available at that time led to the creation of buildings that were not very durable and, after a few years of life, met excessive degradation phenomena and then were quickly dismantled. Contemporary buildings that use composite construction solutions are few and even fewer are the realizations of "all-FRP" buildings. This is due to a lack of acceptance of the material even by the actors of the constructionfield, as opposed to what happened in the marine industry and automotive where they managed to replace metals in a high number of applications.

A very important example of an "all-FRP" building has been completed in the late '90s in the city of Basel by Professor Thomas Keller from the Ecole Polytechnique Federale de Lausanne EPFL. This building is called the Eyecatcher building. It has a structure entirely made of fiber-glass pultruded IPE profiles and the cladding system is composed by panels infilled with aerogels. This envelope solution, in spite of a few centimeters thick, provides a very high value of thermal transmittance comparable to that of much more massive structures made of concrete blocks or bricks. The structure is assembled by bolted connections.

Fig. 4. Examples of buildings partially or entirely made of FRP. On the top-left the Eyecatcher Building that represents one example of a building made entirely by GFRP. On the top-right is the Regent Lighting Center constructed in Basel with a translucent shell of GFRP panels. On the bottom, the roof of the Main entrance of the Novartis campus in Basel, it is entirely made by light-weight GFRP

It is obvious that this solution as well as ensuring excellent performance also allows high levels of prefabrication that affect all the implementation process of the building. It addition to being extremely light and then quickly mountable GFRP buildings can be designed as removable and reusable. The Eyecatcher building was, in fact, already been disassembled and reassembled on one occasion. The use of the pultrusion process ensures the containment of the building prices, a low emissions of CO_2 in the atmosphere [1] and a reduction of human and economic resources during the working phase on the construction site.

Conclusions

In this paper an overview of the potential of the use of FRP structures and "all-FRP" structures is given. These buildings are capable of combining high performance from the structural point of view with a high performance building envelope. Particular reference is made to the low energy consumption for heating and cooling the building despite the low wall thickness. It is nowadays a common impression in research and industry fields, that in the coming years the construction industry will need to invest heavily in such materials because of the technical and environmental advantages that are related to it.

Among the most obvious advantages of using FRP materials in construction, it is possible to highlight:

- A remarkable ease of transportation of building components on site and an easy handling and rapid movement in situ. The panels can be moved by two workers.
- Quick assemblage of the structure.
- Reduced cost of the structure, due to rapid assemblage and a reduction of workforce during the construction stage.
- Reduction of the critical issues and defects related to the creation of handmade artifacts typical of traditional construction materials.
- Reduction of thermal bridges in the structure due to the continuity of structure and cladding componenets.
- Low CO_2 emissions into the atmosphere, through the production process of pultrusion and a high durability of the material over time that reduces the need for maintenance.

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