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Ethylene tetrafluoroethylene (ETFE) material: Critical issues and applications with emphasis on buildings

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ABSTRACT

The present article is a critical review about ETFE (ethylene tetrafluoroethylene) material, with emphasis on building applications since ETFE is promising for the building sector, offering multiple advantages (elastic and low-weight structures, etc.) from different points of view. Selected references about ETFE properties are presented, revealing that ETFE material presents resistance to temperature/aging, mechanical strength and chemical resistance. In addition, studies about light transmission/insulation of ETFE material for building applications are included, showing that ETFE cushion insulating characteristics can be further improved by utilizing additional layers while some studies refer to ETFE decay in terms of light and solar transmittance performances after some months of exposure. Investigations which compare ETFE with glass are also presented, revealing that ETFE offers many advantages, in comparison with glass, from different points of view. A separate part of the article is about ETFE environmental profile and the literature review demonstrates that most of the investigations (which include LCA (life cycle assessment)/environmental issues about ETFE) evaluate embodied energy (the findings show values from 26.5 to 210 MJ/kg). Concerning ETFE applications, the literature review reveals that ETFE can be used for different applications (roofs, façades, atria, in combination with PV (photovoltaic) technology, etc.). Moreover, additional issues (acoustics, shading, etc.) are presented and critically discussed. Furthermore, a separate part with case studies is included. In this way, the present article offers useful information about ETFE, based on different factors, focusing on ETFE applications for buildings and constructions.

1. Introduction

Plastics in buildings offer lightweight and low-cost alternative solutions to glass and other claddings; in this way, plastic materials are useful for building applications, for example for commercial buildings [1]. During the last years, new plastics have been developed, resistant to UV radiation and without showing decoloration, and there is a growth in the variety of the plastics while their lifespan and quality increase. Among these plastics, ETFE (ethylene tetrafluoroethylene) is a promising material that can be adopted as cladding for buildings (and, in general, for multiple architectural constructions), offering around 95% light transmission, flexibility and inspiration for new concepts influencing building structural design [2]. Nowadays, ETFE is considered as one of the most innovative materials in the frame of modern architecture [3] as well as in lightweight architecture with creations of spectacular buildings of various geometric and unusual forms [4].

The development of ETFE, and in general the development of fluoropolymers (polymer materials containing fluorine atoms in their chemical structures), has started several years ago. An overview of the history of fluoropolymers, from the discovery of the polytetrafluoroethylene (30 s) till nowadays has been presented by Teng [5]. Moreover, in the work of Teng [5] it was noted that the existing products can satisfy most of the requirements for industrial applications and the current efforts give emphasis on the reduction of the production cost as well as on the expansion of the market.

List of symbols and abbreviations: BI, Building-integrated; BIPV, Building-integrated photovoltaic; BIPVT, Building-integrated photovoltaic/thermal; CFD, Computational fluid dynamics; CML, CML method; ECTFE, Ethylene chlorotrifluoroethylene; ETFE, Ethylene tetrafluoroethylene; FEM, Finite element method; FEP, Fluorinated ethylene propylene; IR, Infrared; LCA, Life cycle assessment; LED, Light-emitting diode; PE, Polyethylene; PET, Polyethylene terephthalate; PTFE, Polytetrafluoroethylene; PV, Photovoltaic; PVB, Polyvinyl butyral; PVC, Polyvinyl chloride; PVDF, Polyvinylidene difluoride; PVT, Photovoltaic/thermal; TFE, Tetrafluoroethylene; THV, Tetrafluoroethylene-hexafluoropropylene-vinylidene fluoride; TPO, Thermoplastic polyolefin; UV, Ultraviolet

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In the literature several studies about ETFE material have been presented. These studies examine ETFE from different points of view. For example, some investigations give emphasis on ETFE mechanical behavior [6–9] while other studies focus on issues related with light transmission and insulation [10–13]. In addition, some authors examine ETFE material from LCA (life cycle assessment)/environmental point of view [14–17]. On the other hand, in the literature there are some works which: 1) compare ETFE with glass [15,18], 2) present issues about the acoustics of ETFE structures [19,20], 3) examine shading and thermal comfort of ETFE structures [21,22], 4) discuss issues about the inspection of ETFE foils [23]. In terms of ETFE applications, several studies have been presented, including multiple applications such as ETFE façades [24], ETFE roofs [14], ETFE atria [25] as well as configurations which combine ETFE with PV (photovoltaic) technology [26–28].

Based on the above mentioned, it can be seen that ETFE material presents interesting characteristics and useful applications, including the building sector. In the literature, there are few review articles about ETFE: Hu et al. [29] presented an overview about buildings with ETFE foils with emphasis on material properties, architectural performance, structural behavior and sustainable ETFE structures; Hu and Jiang [30] conducted a review about the production and the market of ETFE; Chilton [31] presented a state-of-the art about lightweight envelopes based on ETFE. Thereby, there is a need for more review articles which present an overview of ETFE material from different points of view. In the frame of this scope, the present article is a critical review about ETFE material, discussing different issues:

1) General characteristics for high-performance materials/configurations for buildings.
2) Requirements specifically for membrane configurations (roofs, façades, etc., in terms of aspects such as material selection for membranes).
3) Mechanical and other critical properties of ETFE material (light transmission, insulation, etc.).
4) Acoustics related to structures which are based on ETFE.
5) Shading issues about configurations including ETFE components.
6) Inspection of transparent construction materials.
7) Issues about ETFE material from LCA/environmental point of view.
8) Applications (requirements in terms of claddings; studies about ETFE façades, roofs and atria; combination of ETFE with PV or PVT (photovoltaic/thermal), etc.).
9) Case studies based on ETFE systems (for buildings and architectural constructions) that have been already developed.

In addition, a critical discussion is provided and by considering that:

1) There is a need for reduction of the energy consumption in the building sector in order to reduce CO_2 emissions. Passive design approaches can offer multiple advantages (energy savings with low extra investment, etc.) towards green buildings and sustainable constructions [32].
2) ETFE is a promising material in the frame of environmentally-friendly buildings and constructions [2].
3) In the literature there are few review articles about ETFE, it can be seen that the present study provides useful information about ETFE, based on different points of view.

More specifically, in the present article, the major part focuses on building applications and environmental issues, taking into account the importance of eco-friendly constructions in the building sector. Within the frame of this concept, multiple ETFE configurations and examples which combine ETFE with PVs are presented, highlighting the role of renewable energy sources in the frame of sustainable constructions and buildings. Finally, the part of the case studies verifies, based on projects that have been already developed and applied in practice, the connection of ETFE material with renewable energy systems and eco-friendly constructions.

2. Literature review

2.1. Characteristics of high-performance materials/configurations for building applications

Paech [24] noted that structural high-performance materials present high ratio of structural strength to dead load and the application of these materials is optimal when they are under pure tension (utilizing the full structural capacity by omission of bending moments and any stability issues). However, high-performance is not only about the structural properties. High-performance is also related, for example, with the fact that a material or composite of materials is designed and produced to have specific characteristics (e.g. specific color, acoustic damping, transparency or translucency, air permeability, etc.). Moreover, Paech [24] mentioned that selective coatings are sometimes part of high-performance materials in order to affect the properties of a specific building (example: coatings for the improvement of the interior climatic conditions).

Related with the above mentioned factors, some additional issues are following presented:

- Design considerations for the roof-to-wall interface (the roof and wall design should be able to resist the fundamental forces as outlined by the applicable building code. Parameters such as building overall height, use, roof slope, location, structural type and shape should be taken into account for the development of the roof-to-wall interface) [33].
- Heat, air and moisture factors (for the protection of the quality of the interior environment and building enclosure assemblies from the deleterious effects of moisture and air) [33].
- Adaptive or moveable elements impose specific demands in terms of the selected materials (sometimes it is necessary to have specific geometrical arrangements) [24].
- Adopting membrane materials for façades is a more economical solution than using traditional cladding materials, especially when there are reduced requirements on the envelope system (for example, pure shading or balancing of thermal peak loads and simple wind or visual barrier) [24].
- Use of advanced façades which are cost effective and they offer environmental quality, life-cycle savings and energy efficiency [34].
- Façades should be able to respond and adapt to the variable exterior conditions and to the needs of the occupants [34].
- Special requirements depending e.g. on the height of the building (specific case: for example, high-rise buildings) are necessary for certain cases [34].
- Adoption of solutions which combine façade with ventilation [34].
- Use of systems that include combination of a façade with production of energy (active façade systems) [34].
- Utilization of façades that offer solar control and/or daylighting [34].

The degree of influence of the above mentioned parameters is associated with the specific case of a building/construction. As a general comment it can be said that the high-performance materials/configurations in the building sector include multiple issues, ranging from the structural strength of the materials to strategies which propose multifunctional façades (for ventilation, daylighting control, energy production, etc.).

In the report of BASF [1] it was noted that the envelope of a building should control heat flow, moisture flow and air flow and at the same time it should offer structural integrity and protection from wind, rain, snow, hail, dust, pollutants, allergens and pests. A high-performance building envelope is defined by its ability to achieve these goals [1].