A STUDY ON THE APPLICATION OF THE ETFE FILM MATERIAL IN "MICRO-ARCHITECTURES"

Changzheng GAO[1], Yimeng ZHANG[2]

With advantages such as durability, environmental protection, good light transmission and self-cleaning, the ethylene tetrafluoroethylene (ETFE) film has been wildly used in large-scale buildings at home and abroad in recent years, so it has very good development prospect. In this paper, the ETFE film material and its structure type are briefly described. The advantages of ETFE film are analyzed in terms of the application performance, visual form, low carbon emission and energy saving. The concrete design method of micro-architecture with application of ETFE film material is introduced based on the development trend of modern architectures. In addition, main methods for the external "paper folding" form; light steel skeleton structure and modularization construction are discussed, with a view to promoting the development of ETFE film material to a certain extent.

Keywords: ETFE Film Material; Performance Application; Micro-architecture; New Building Materials

1. Introduction

The architect Richard Rogers once said: "Architecture will no longer be represented by its size and volume in future as the traditional architecture does. Instead the lightweight structure and multi-layer superimposed transparent body will be employed to present its image."[1]. The film structure is a kind of spatial structure which is formed by combining high strength flexible film material with the supporting system. It has stable surface with certain stiffness and can withstand a certain external load. This film structure uses film materials other than traditional building materials. Its weight is only one-thirtieth of the traditional building. In addition, it can fundamentally overcome the difficulties in realization of the long-span (no support) building, and can create a huge unobstructed visual space. It is light, flame retardant, energy-saving and is easy to produce, fast to install and safe to use, thus allowing it to be widely used around the world.

At present, many gymnasiums, exhibition halls and other large public buildings at home and abroad have achieved artistic beauty by using of ethylene tetrafluoroethylene (ETFE) film in their exterior facades and roofs, so it has a

[1] College of Architecture, North China University of Water Resources and Electric Power, Zhengzhou, Henan, China, e-mail: 380636290@qq.com

[2] College of Architecture, North China University of Water Resources and Electric Power, Zhengzhou, Henan, China

promising application prospect. But this new material is mainly used in the national large-scale sports buildings and rarely used in other categories of buildings. In the 21st century, with the rapid development of science and technology, many types of contemporary architecture show a microminiaturization trend. Micro-architectures are not only a supplement to the huge architectural form, but also show its own unique charm [2]. In this process, the micro-architecture not only shows the infinite possibilities of micro-trend, but also materializes a variety of clever ideas. It is applied in a wider range of areas at the same time. For example, the application in the field of public buildings, community service buildings, mobile buildings, contingent buildings, landscape structures, landscape architectures and villa architectures proves to be successful cases of distinctive characteristics. In the future, micro-architectures will continue to innovate in a diversified, high-tech, low-carbon and recyclable direction. Experiments are made constantly to explore a variety of new forms. In this process of continuous experiment, to create the micro-architectural form with a unique shape by means of new material and technology such as the ETFE film material is the main development direction discussed in this paper.

2. Introduction and structure types of ETFE film material

2.1 Introduction of ETFE film material

ETFE is an ethylene-tetrafluoroethylene copolymer, which can be processed into transparent ETFE film. The ETFE film material is of typical non-woven category without base cloth. It can be directly made into film from raw material. Light and transparent, it becomes a new type of film product used in building structures after PVC (polyvinyl chloride) and PTFE (polytetrafluoethylene) film materials [3].

In foreign countries, ETFE film has been widely used in some public buildings and facilities. Compared with these countries, China starts late in the design and construction of buildings with this film. Nowadays, in China, the PVC film has been widely used in large-scale public buildings such as "Bird's Nest" and "Water Cube". However, the PTFE film material is rarely used in micro-architectures. With growing attention to the micro-architecture, many architects and engineers begin to focus on how to apply the new film building material ETFE into micro-architectures.

2.2 Types of ETFE film structure

The ETFE film structure is a brand new form of building structure, which integrates architecture, structural mechanics, fine chemicals and materials science and computer technology into one, thus has a high technical content [4]. It can be divided into three forms in terms of the structure: skeleton-type film structure, tension-type film structure and inflatable film structure.

"Skeleton-type" film structure

The "skeleton-type" film structure has a rigid frame. It can be made of steel, aluminum or wood. The film surface is fixed on the framework and the shape is generally regular. With high economic efficiency, short construction period and other advantages, it is widely used in all sizes of space. This structure is used in the United States Exhibition Hall of the World Expo held in Osaka in 1970, which marks the beginning of this film structure’s application

"Tension-type" film structure

The "tension-type" film structure consists of the film material, wire ropes and pillars. The film is tensioned with wire ropes and pillars to achieve a stable form. Its shape is creative and beautiful, but high requirement is needed during construction to ensure high precision, so the cost is slightly higher than the "skeleton-type" film structure.

"Inflatable" film structure

The "inflatable" film structure fixes the film material around the roof structure and then uses the air supply system to increase indoor pressure to a certain degree, producing a pressure difference inside and outside the roof to resist the external force. It can obtain larger spaces without any beam and pillar support and the construction is rapid. However, the blower should run continuously, so the cost for operation and post-maintenance is high.

To sum up, these three structural forms have their own advantages and disadvantages. In the actual project, we can select the form of ETET film structure according to the needs and the situation at the scene.

3. Main advantages of the ETFE film material in architectures

The ETFE film structure is a kind of spatial structure which is formed by combining high strength flexible film material with the supporting system. It has stable surface with certain stiffness and can withstand a certain external load. This film structure uses film materials other than traditional building materials. Its weight is only one-thirtieth of the traditional building. It is light, flame retardant, energy-saving and is easy to produce, fast to install and safe to use, thus allowing it to be widely used around the world. In China, this structure is only used for large-scale sports venues, a small number of public recreation plaza, exhibition venues and other fields at present. When used in ordinary buildings, it can present the effect which the traditional material cannot realize.

3.1 Application performance advantages of ETFE film material

The ETFE film can be obtained by extrusion molding of ETFE particles after being melted at high temperature. Its transparency can reach 95%, thus is commonly known as "soft glass". According to the requirements for the desired effect of the building, ETFE can be mixed with additives of pigment to get ETFE

products with a variety of colors. In addition, printing can be performed on the surface to adjust the light transmittance so as to effectively prevent the invasion of harmful ultraviolet light [5]. It can be seen from Fig. 1 that the light transmittance of the ETFE film for each frequency band of light is high. If the ETFE film is used in the subway station entrance as a surface material, the internal light will still be very close to the natural state [6].

The melting temperature of the ETFE film material is 260 ~ 270 ℃ and the thermal decomposition temperature is 350 ~ 360 ℃. Under normal circumstances, thermal decomposition aging and melting will not happen to the ETFE film. Oxygen concentration required for burning of the ETFE film material is higher than the atmospheric oxygen concentration, so it belongs to the flame retardant material, reaching the B1 and DIN4102 fire rating standards. It will not melt or drop in burning and will automatically extinguish after removed from fire. With these excellent flame retardancy and high temperature resistance, the ETFE film material can meet the fire protection requirements of buildings [7]. With light weight, flexible structure and a large deformation capacity, it has excellent seismic performance. It can be seen from Table 1. That the overall performance of the ETFE film material is in no way inferior to glass and other conventional membrane materials.

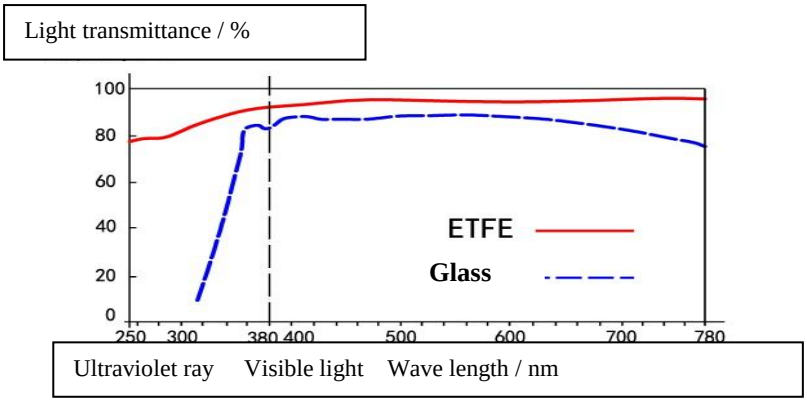

Fig. 1. Comparison of transmittance between the ETFE film and glass

Table 1.

Comparison of composite performance of the ETFE film material and conventional membrane material

Categories	ETFE film	PC board	PVC film	Ordinary glass
Transmittance/%	95	89	95	80
Elongation at break /%	400	105	200	-
Density/g/cm^3	1.75	1.2	1.4	2.5
Thickness/mm	0.05 ~ 0.3	2 ~ 15	0.05 ~ 0.2	3 ~ 19
Deformation capacity	Excellent	Fair	Good	Poor

Impact resistance	Good	Excellent	Good	Poor
Self-cleaning performance	Good	Worse	Poor	Worse
Melting point/℃	260 ~ 270	220 ~ 230	180	720 ~ 730
Fire resistance	Flame retardant	Flame retardant	Flame retardant	Non-combustible
Recycling	Yes	No	No	Yes

The ETFE film air cushion is made of thin film and its thickness is measured with micron. It is so light that its mass is usually negligible. Similar to the flexibility of the structure, the ETFE cushion also has a damping effect in the sound, especially in low frequency sound. From the acoustical point of view, because the cushion can absorb the internal noise, the indoor hearing environment in the film material structure will be more comfortable than that in the glass and other hard materials structure. At the same time, harsh and high frequency sound can be avoided if we install the resonator in the structure. The purpose of selectively absorbing sound of different frequencies can also be achieved through adjusting the air volume of the inflatable duct under the cushion placed in the bottom of the ETFE air cushion film structure [8].

3.2 Visual morphology advantages of the ETFE film rich forms

Nowadays, with the rise of domestic construction quality and the improvement of people's living standards and cultural quality, the traditional building materials and architectural forms cannot meet the needs of urban modernization and visual aesthetics. The ETFE film is soft and has a high tensile strength, and it can be processed into any shape according to the actual needs. The building surface made of ETFE film combining with the appropriate internal structure support can create a rich appearance effect, thus highlighting the geographical characteristics of buildings at different places.

The public space work "Boundless" created by AD was shown in the 2016 Milan Design Week. It is located in the central courtyard of the University of Milan Cortile d'Onore. Under the exhibition proposition of "open the border", the designer tries to capture the change of environment under influence of the wind and light and creates a warm, smart, free new space, bringing an open atmosphere for exchange and dialogue and putting forward new ideas. A curtain made of ETFE material extends from the traditional building archway to the ground of the courtyard, forming a new triangular space. The space changes with the transmission of the sunlight and the flow of wind, becoming a public place for daily recreation. The use of the ETFE film in the design explores new ideas for future building design.

Fig. 2. The central courtyard of Cortile d'Onore of the University of Milan

Transparent visual experience

As the ETFE film has a good light transmission characteristic, in the daytime, the sun can penetrate through the film from outside and enter the inside of the exit by diffuse reflection, bringing abundant natural light to the room. At night, different colors can be presented with the change of the lamplight with the help of the lighting system and CNC technology. The internal light can penetrate through the film from inside, making the entrance and the exit as bright as a lantern, which adds beauty to the city's night scene and improves visual experience of people in the city.

French designer Phillipe Stark is famous for his furniture and products design. In 2015, he entered construction field and his first project is Le Nuage, which is the first inflatable film building in France. This project tested the innovative approach. The design focuses on creating transparent effect and features light bubble-like façade. ETFE was used to create inflatable transparent bubbles, giving the building a sense of lightness. People can experience different visual effects from outside or inside.

Fig. 3. Le Nuage fitness center

3.3 Low carbon and energy saving advantages of the ETFE film material

The ETFE film features the easiest recycling and best environmental protection and energy saving property among all the film materials [9]. First of all, the ETFE film material has a certain self-cleaning and high stain resistance and it is easy to clean. Rainwater can wash away most stains, which can reduce post-maintenance cost. In addition, daily maintenance is rarely needed. Secondly, the recycled ETFE film material can be processed into new film materials after hot-melting or impurities separating, which is a truly recyclable environmentally friendly product. Thirdly, the ETFE film, the steel skeleton and the steel rope can be produced in plants and assembled at the construction site, so the construction period is shorter than traditional building. At last, the ETFE film has excellent stability and chemical resistance. The results of artificial aging test and outdoor exposure test showed that, after long-term outdoor use, the light transmission performance, strength and elongation of the ETFE film has no significant decline, so it is ideal for the facade of micro-architecture.

In general, the ETFE film structure can be rapidly installed and is easy to dismantle, which is time-saving. From production, construction to recovery, carbon emissions in the whole process are much lower than that of ordinary steel and glass structure. The usage of the ETFE film material in micro-architecture is in line with the current trend of development of green buildings and meets the requirement "build a resource-saving and environment-friendly society" proposed by the State, which can achieve sustainable development.

4. The technical practice of the ETFE film in the design of micro-architecture

Under the support of advanced materials and technology, micro-architectures can achieve all kinds of complicated forms. Some micro-architectural forms, which tested structural characteristics through continuous experimental exploration, promote the continuous development of this design tendency. Thus, this direction is of important research significance. It is worthy of an in-depth analysis.

Main approach of the ETFE film material is explored in its design practice in micro-architectures, which is reflected in the following aspects:

4.1 Manifestation of the "paper-folding" shape of the façade

Micro-architecture with the shape of paper folding uses a single layer of film that does not require an inflatable system. The film surface is straight one instead of the general curved one created by tension, thereby reducing the stress on the film surface and the possibility for creep and strain. The steel truss structure is used inside the architecture to directly support the film material. The

entire steel truss structure (Fig. 4) is a woven form consisting of prefabricated members based on certain modulus. At the same time, each rhombus can be seen as the basic unit of steel trusses. A diagonal steel stringer of each rhombus is used as a "ridge line", and the other two corners are the low points of the film surface. The trusses are interconnected with the ETFE film unit by interspersing with each other, whereby the ETFE film is stretched to stimulate the shape and form of "paper-folding".

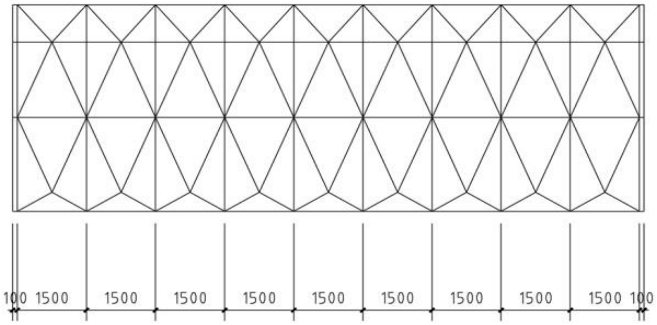

Fig. 4. Diagram of dimension of side façade of the weaving-type truss structure

The film surface is not parallel with the ground at any point. The facade and the top surface have the same shape and form. In rainy days, rain on the folded top surface can quickly flow to the ground, thereby reducing the pressure on the film surface. In addition, non-linear texture of paper can be simulated on the surface of the ETFE film. This fine detail can well demonstrate the thin and transparent characteristics of the “paper” as well as the intensity and lightness of “paper-folding" structure.

For example, the German-Chinese House at the Expo 2010 (Picture 5) is a two storey bamboo-structure environmental protection building covered with the film. It is a micro-architecture with a construction area of only 300m^2. The bamboo is used to support the whole system and is connected with each other through steel nodes. The roofing uses film materials. The wall structure consists of natural bamboo and transparent and lightweight new material-ETFE film. The use of film material ensures the internal light transmission of the building. In addition, the high tensile strength characteristic of film material helps achieve the rich and varied architectural appearances. It is a typical case of the film structure used in micro-architectures in China.

Fig. 5. Appearance of the pavilion using film material

4.2 The support of the internal light steel frame to the film structure

The construction, installation and control of the ETFE film structure focuses ensuring the coordination work of the film material and the skeleton support system. The film is stretched under the action of the support structure and its own gravity to form a fold without wrinkles. Thus, the connection between the film material and the support frame become the key content of the installation and construction quality control [10].

In the design of micro-architectures, light steel structure can be adopted. The roof of this structure can be used the top surface as well as the facade of the building. The facade and the top surface are formed by cross-weaving of steel diagonal bars (Fig. 6). The light steel structure is similar to the steel truss structure, but the former is mainly used to support the steel truss. The steel diagonal bar is connected through nodes of the three-dimensional space, which forms diamond-like woven grid structure, and has a very good stability [11]. At the same time, the size of ETFE film materials and steel components is standardized as far as possible to reduce the difficulty in the construction process.

At present, this structure is typically represented by the reconstruction project of Australian Adelaide Entertainment Center (Fig. 7). It is designed by DesignInc. Light steel skeleton is its main support structure. The light steel structure is a young steel structure system with promising prospect. It consists entirely of steel component system. Steel ribs are made of super anti-corrosion high-strength cold-rolled galvanized steel pipe. The whole structure is light and has high strength. It has free structure and form. Combining with the ETFE film material, it creates a semi-transparent and flexible "dynamic dome space", becoming a local landmark architecture. With flexible functions, it allows a variety of performance patterns, which is applicable to micro-architectures at limited land area.

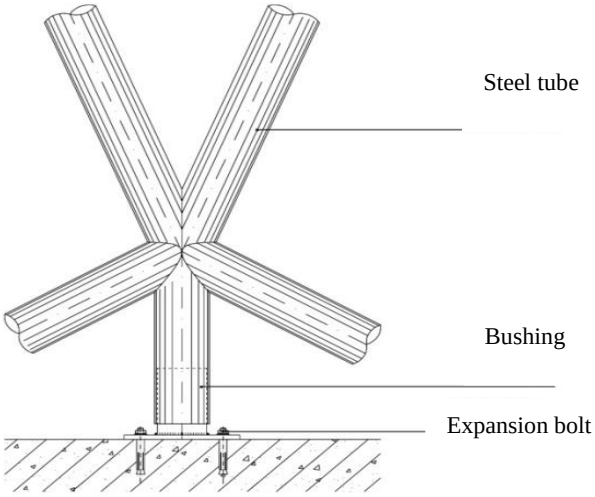

Fig. 6. Diagram of nodes in the light steel skeleton

Fig. 7. The reconstruction project of Australian Adelaide Entertainment Center

4.3 The application of integral modularization technology

The combination of ETFE film materials and the woven steel structure uses modular design (Fig. 8). Modular scale is based on the size of the human body and construction equipment. A reasonable combination mode is selected through the computer simulation analysis of steel components to form the modulization of steel components. Triangular ETFE film components are then prefabricated on the basis of this structure. Two modular components are then assembled to form into a module. The assembly is performed at the construction site according to plane size of the subway, which can effectively shorten the project cycle.

With modular design, the ETFE film material and woven steel structure can be combined and used in large-scale sports buildings as well as other micro-

architectures after changing modulus or other forms according to actual needs.

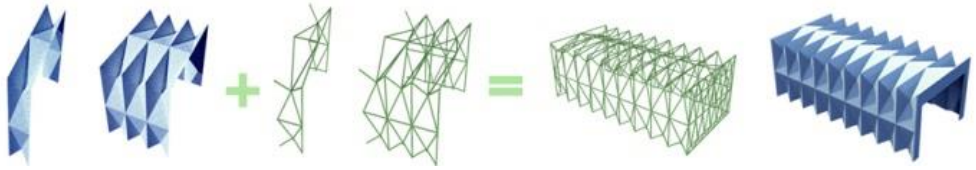

Fig. 8: The Application of modularization

For example, roof of the gas station of CEPSA (Fig.9) designed by Saffron Brand Consultants and Malka+Portús arquitectos uses high-tech tetrafluoroethylene (ETFE) materials, which has self-cleaning, light and recyclable features. Its structure is assembled using modular approach to accommodate different gas stations. The 100% transparency of tetrafluoroethylene (ETFE) reduces the use of artificial lighting, thereby reducing the cost of gas stations. At the same time, innovative plastic cushions turn the front courtyard into a place full of light and with good ventilation.

Fig. 9. The gas station of CEPSA

5. Conclusions

New materials and technology has always been the development direction and leading sign in the construction field. Nowadays, China is vigorously promoting environmentally friendly materials and green building. The application of the ETFE film is an important factor in promoting the architectural revolution [12]. The comprehensive performance of the ETFE film material is better than the traditional glass-based materials in terms of basic functions. As for the requirement of the building appearance, the ETFE film material structure is no longer confined to the regular shape. On the contrary, it can present more iconic

and characteristic shape by combining regional cultural characteristics and traffic function requirements. In terms of the requirement of energy saving, the ETFE film material can be recycled, and it is easy to dismantle, build and maintain [13]. With the development of new material, technology and process, the ETFE film material will not be limited to application in large buildings such as the "Bird's Nest" and "Water Cube", etc. It will be gradually applied in micro-architectures. Architectures made of ETFE film material will become more and more common.

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