ETFE – A Building Material for the New Millennium

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INTRODUCTION

A relatively new material to the construction industry, ETFE is a lightweight transparent material that is taking the world by storm. ETFE provides an innovative, cost effective, lightweight cladding solution for modern Architecture. Effective thermal performance and high light transmission enable a wide range of applications where traditional materials such as glass would not be possible.

ETFE is an acronym for Ethylene-tetraflouroethylene – a modified flouropolymer resin of the same family as PTFE (also known as Teflon™). ETFE for construction purposes is most commonly produced in very thin sheets by extrusion which are manufactured into cladding elements called Foils.

ETFE Foils can be manufactured in endless varieties of size and shape enabling much greater span distances without intermediate support structures. This enables designers to incorporate cladding with structure to create structures that are extremely lightweight, simple and elegant. The Foil constructions can either be fully pre-fabricated and transported to site as modular units or they can be assembled on site.

Major Benefits of the ETFE system include:

- Ultra light weight system
- Wide Spans possible
- Minimal support structure
- High light transmission
- Excellent thermal insulation
- Suitable for non-planar applications
- Non-uniform shapes
- Alternative to glass

DESIGN PRINCIPLES

The principles behind Foil cushion design are not new. One of the first examples of a structure with this type of cladding was at the 1970 World Expo in Tokyo where ‘cushions’ manufactured from Polyester were used as a cladding to a Spaceframe.

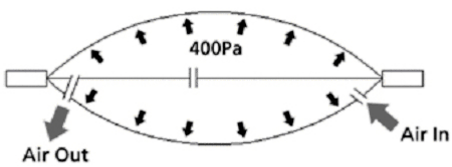

Figure 1: Foil Construction

Essentially, two or more layers of an impermeable fabric or film are clamped around the edges and the middle inflated to create a Foil shape. The type of clamping mechanism varies but most commonly consists of special aluminium boundary profiles, which are supported by steel or timber substructures or cable nets.

ETFE is an excellent choice for this type of system. It exhibits a high degree of material toughness and low tear propagation. It shows signs of work hardening over an approximate 400% elongation range – which also allows a high degree of flexibility in terms of overall system deflections.

Resistance against UV, weathering, chemical attack and possessing a low surface friction coefficient also contribute to material advantages. The air pressure inside the system prestresses the fabric and the curved, foil shape is achieved. Typically, an internal pressure of between 200 and 750 Pa is used, depending on the shape and size of the system.

As external loads such as snow or wind are applied, the air pressure inside the foil increases. The increased air pressure transfers the load to either the external or internal faces of the Foil which act as 'catenaries' taking the loads to the perimeter frame. In the event of a loss of internal pressure or if the applied load exceeds the inflation pressure, the top face inverts and the applied load is resisted directly through catenary action.

$$R = \frac{s^2}{8.d} + \frac{d}{2} \qquad P = \frac{T_1}{R_1} + \frac{T_2}{R_2}$$

where:

R = Principal radius of curvature for each face
s = Span of system (usually the smallest dimension across the system)
d = rise of foil surface (aka dip)

P = Internal pressure
R_1 and R_2 = the principal radii of curvature for the two faces
T_1 and T_2 = the surface tensions in these directions

A typical panel 3m wide x 40m long might have a central rise of 270mm, an inflation pressure of 500Pa and an initial equilibrium stress of 10N/mm^2 across the system's principal radius of curvature. Final stresses in the system are calculated using computer modelling based on stretch characteristics. In areas of high wind pressures or high snow loads, cables can also be introduced to the system to relieve some of the stresses in the Foil system.

Like most lightweight systems, the forces in the pneumatic system eventually need to be resisted by a support structure. The resulting loads are a function of the shape of the Foil (see Figure 1) and the applied loads. Generally however, adjacent foils tend to balance out the loads generated by the shape of the Foil itself, with the supporting structure needing to be designed to resist any applied loads such as wind. Perimeter structures need to be designed to resist both the forces from the Foil shape and the resultant forces of any applied loads. It is sometimes necessary to position some cables in the centre of the Foil construction so that in the case of a cushion failure, un-balanced loads from adjacent Foils do not cause failure of the support structure.

Foil constructions can, in theory, be manufactured to any size and shape. The limiting factors however are the size of the perimeter framing, the rise of the Foils, the management of the internal pressure and the costs associated with the perimeter clamp details. The ETFE material itself is sourced on a roll approx 1.5m wide. Strips of ETFE can be joined together to form complex 3D shapes. The most common is rectangular, however other shapes such as triangles, hexagons and octagons can also be manufactured easily. Typically, the foils are patterned in a similar manner to conventional membrane structures.

Figure 2: Eden Project, Cornwall, UK

BASIC MATERIAL PROPERTIES

Characteristic	Units	Test Method	Results	
Thickness	µm	DIN 53 353	100	Up to 250
Tensile Strength				
longitudinal	N/mm^2	DIN 53 455	50	50
transverse	N/mm^2	DIN 53 455	45	45
Elongation at break				
longitudinal	%	DIN 53 455	400	400
transverse	%	DIN 53 455	450	450
Tensile Strength at 10% Elongation				
longitudinal	N/mm^2	DIN 53 455	25	25
transverse	N/mm^2	DIN 53 455	20	25
Modulus in Tension	N/mm^2	DIN 53 457	1000	1000
Tear Resistance				
longitudinal	N/mm	DIN 53 363	500	400
transverse	N/mm	DIN 53 363	500	400
Shrinkage				
longitudinal	%	150°C/10min	2.5	2.5
transverse	%	150°C/10min	0	0
Density	kg/m^3	DIN 53 479	1750	

Table 1: ETFE Material Properties

INFLATION SYSTEM

The inflation system associated with the ETFE Foils maintains the air pressure at a constant level. In its most basic form, the inflation system consists of a centrifugal fan unit with humidity controls and filters to prevent moisture and dirt from entering the Foil units.

In the more advanced forms, the inflation system can also be linked to sensors that would allow the inflation system to vary the internal pressure of the Foils to cope with applied loads.

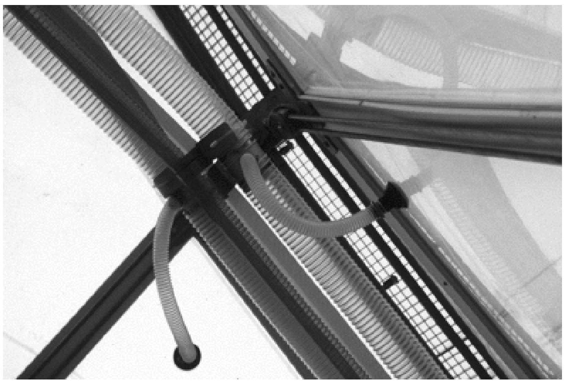

Figure 3: Typical Air Supply Detail

The inflation units must usually operate constantly in order to cycle air through the system and to allow for any leaks within the system. However, in the event of the inflation unit not operating (for example due to maintenance or power loss), the connections to the Foil incorporate one-way valves which prevent air pressure loss. Generally, for areas under 250m^2 only 1 fan is required. For larger areas, 2 fans are normally used per 1000m^2 of Foil system. This enables one fan to be used as a backup.

OPTICAL QUALITIES

Depending on the type of material, ETFE has a very high degree of light transmission. There are several different types commonly available:

Transparent:
Very high transmission of visible and infra-red spectra. Lower but still high transmission of UV spectra. Ideal for use in Northern Hemisphere or applications where plants / grass need to grow beneath the system. Also ideal for animal enclosures.

Opaque:
Approx 40% transmission of visible light spectrum but greatly reduced UV transmission. Ideal for use in southern hemisphere or areas where UV light blocking is desirable.

Printed:
Most commonly consists of transparent film printed with reflective silver dots 15mm diameter at 45mm centres. Average light transmission 60%. However, light transmission through silver areas only 30%. Different print styles are also possible – contact your local Skyspan office for further information.

FIRE

ETFE Foils have been extensively tested at several institutions worldwide. As the material approaches its melt temperature (approx 275°C), the material softens. The internal air pressure of the Foil causes the ETFE to stretch beyond its elongation limits, holes form and the Foil fails. This effectively causes venting of the hot air / fire below. As the ETFE material is so thin and light, any unattached fragments tend to get carried upwards by the hot air rather than dropping to the ground. Under direct flame, the ETFE will burn but will self-extinguish quickly.

This 'self venting' nature of the ETFE prevents the build up of superheated gases beneath the system. This prevents 'flashpoint' – where the air temperature inside causes spontaneous combustion any flammable materials inside.

The by-products from fire are toxic fumes including Carbon Monoxide (CO) and Hydrogen Fluoride (HF). However, as the ETFE Foils have a very low mass-volume ratio, these by-products are usually insubstantial.

ETFE Foils are classified as Fire Rating B1 to DIN 4102-B1 – Flame Retardant.

ACOUSTIC

Due to its light mass-volume ration, the acoustic performance of ETFE Foils is usually fairly poor. However, acoustic performance is a perceived performance factor and the acoustic transparency of ETFE Foils can be an asset. For example, public spaces such as grandstands, swimming pools and shopping malls can benefit from an acoustically transparent roof as loud crowd noises are vented from the area. However, office spaces, which tend to be quiet also require acoustic insulation to prevent noise ingress into the space. ETFE Foils with their low mass usually perform poorly in this type of application.

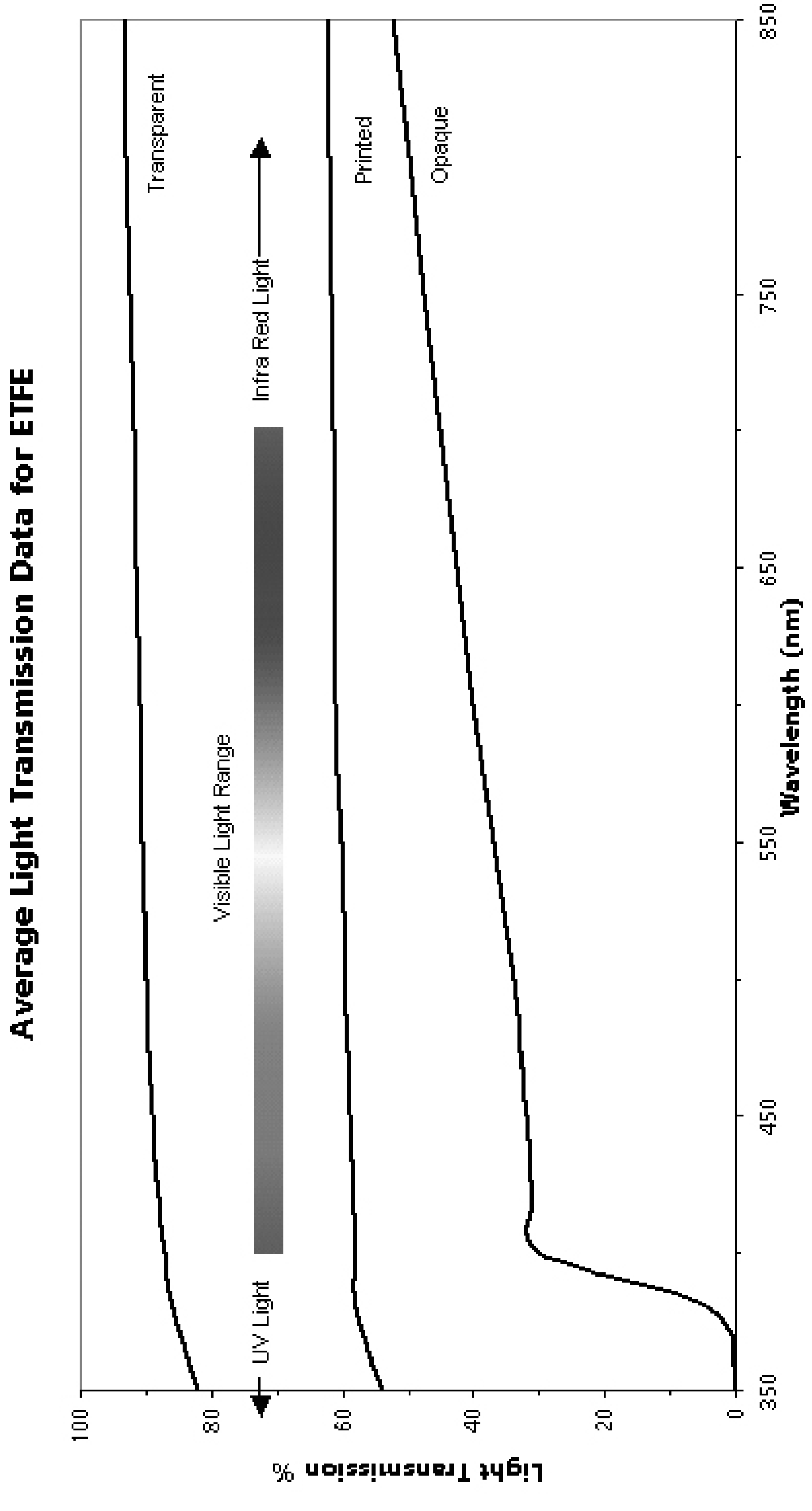

Figure 4: Average Light Transmission Data for ETFE

One other consideration of ETFE Foils is the acoustic performance in rain & hail conditions. As can be imagined, the taut skin of the outer surface can create significant noise under these conditions. Noise levels of up to 85dB can be sustained under heavy rain. For a light drizzle or rain, a reduction of approx 30dB may be achieved. However, overall performance of a space can be compensated for by appropriate consideration of other finishes.

Figure 5: NSSC Rocket Tower, England

WIND

The nature of the ETFE roofing system is that it is inherently quite stiff but very light. However, like most lightweight systems, it is prone to deflection. This is usually controlled during the design stage to fall within acceptable limits. The stiffness of the Foils is governed by the internal air pressure of the Foils and shape of the system. The Foils may be made stiffer by increasing this air pressure. If required, an air pressure sensor may be fitted which automatically increases the air pressure inside the Foils to control excessive deflections in the system.

SNOW

Applied loads such as Snow can also be carried by the ETFE system although the supporting structure needs to be designed for such loads. Under excessive loads, the top layer of ETFE may invert allowing all the layers to act in under Tension – see section on Design Principles.

VANDALISM AND DAMAGE

The ETFE material is extremely resistant to accidental damage. However, it can still be prone to damage from sharp objects such as knives or other pointed instruments. However, the tear propagation of the material is also quite low so that, in the case of a rupture, the hole will not spread.

Damage can usually be separated into three types; Human, Environmental and Animal. Human damage is usually the easiest to control by limiting the amount of access possible to the area. Environmental damage can be caused by flying sticks etc. However, the probability of this type of damage is usually quite low due to the curved nature of the outer skin and the inherent toughness of the material – sharp objects need to hit almost exactly normal to the surface to cause rupture. Animal damage is the most common form of damage. This type of damage has been successfully limited in the past by stringing fishing line along the length of the perimeter clamp mechanism – thereby limiting the animal access possibilities.

THERMAL INSULATION

The thermal properties of ETFE Foils are dependent on the number of layers within the Foil itself. Air is effectively trapped within the system so that convection movement of heat is limited. Thermal performance of Foils will vary across the system from mid-depth of the Foil to the perimeter clamps. U values depend on the shape and size of the Foil used – for an accurate estimate of a U value for a particular size and shape of Foil, please contact your nearest Skyspan office. However, a typical U value might be $1.9 W/m^2K$ – based on a three layer system horizontally. This is roughly equivalent to a high performance double glazing system. Again, performance can be compensated for through appropriate consideration of other finishes within the space considered.

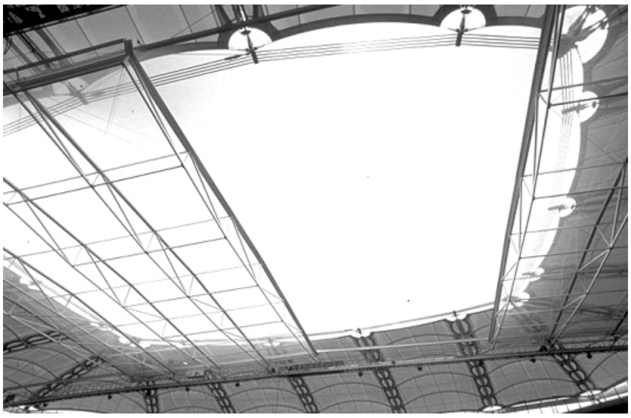

Figure 6: Garry Weber Stadium Retractable ETFE Roof, Germany

RECYCLING AND ENVIRONMENTAL ASPECTS

ETFE can be easily recycled by heating it to melting temperatures and adding to virgin ETFE at the point of manufacture. Foils may also be disposed of in a landfill situation – apart from a very small amount of Hydrogen Fluoride gas (HF) released over time, the material is essentially inert.

REPAIR AND MAINTENANCE

Damage may be repaired by the application of special ETFE Repair tape which is easily available. More extensive damage may require the replacement of an entire panel.

Periodic inspections are recommended to ensure that small holes / air leaks have not formed. Periodic maintenance of the inflation system is also recommended.

In the event of an entire panel needing replacement, this can be performed usually with the minimum amount of effort. For example, a 3m x 3m panel of 3 layer ETFE Foil weighs approximately 10kg not including the clamping mechanism.

CONDENSATION

Condensation is avoided on the internal surfaces of the Foil system by controlling the humidity of the internal air. As the internal air temperature of the Foil is usually similar to the internal air temperature of the enclosed space, condensation does not usually occur on the surface of the Foil.

Figure 7: Prienavera Swimming Pool, Germany

CLEANING

ETFE has a very low surface friction coefficient that allows easy cleaning by natural rainfall. The curvature of the Foils promotes this cleaning action although care must be taken to ensure positive water runoff angles at the edge connections so that dirt build up cannot occur in these locations. Periodic cleaning may be required depending on location. The need for this should be assessed during the periodic inspections.

Cleaning of the internal face is helped by the low skin friction of the system. However, a normal cleaning regimen should apply.

COSTING

Due to the nature of the system, costing of ETFE Foil systems and all other membrane materials must be looked at as an entire cladding solution rather than as a direct replacement for any particular material. Lifetime costs must also be considered as factors such as maintenance costs for the fans and replacement costs may

ACKNOWLEDGEMENTS

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REFERENCES

ETFE Foil Cushions as an alternative for glass roofs and atria by Buro Happold Consulting Engineers for the DETR.

Document 1: General Guide
Document 2: Detailed Materials Investigation
Document 3: Buildings In Use
Document 4: Design Guide

Nowofol: strength data on 50, 100, 150, 200 micron foil samples.