MATERIAL
Abstract. This paper is concerned with the materials currently in use in the field of membrane architecture. The first section describes the basic characteristics membrane materials should meet to be able to be applied in membrane structures. The second section discusses the most commonly used fabrics and recent developments in this field. The third section discusses ETFE foils, a relatively new material applied in membrane structures.
1 A DISTINGUISHING BUILDING CONCEPT

The first TensiNet Symposium is about the design of membrane structures, and this paper about the materials used. Conventional buildings are distinguished on the basis of the material used. One can choose to have a timber or a concrete building, thereby implicitly choosing a construction principle. This is slightly different with a membrane structure because there are numerous materials that can be applied as a membrane material while the construction principle remains the same. So, unlike with conventional buildings, membrane structures are distinguished on the basis of their structural concept.

The membrane principle is, however, only one of the features of membrane structures. We also want to create a stable shape under external load. If we make a hanging covering of low weight (with single curvature), spanning say 20 meters, this certainly will take up external load by means of the membrane principle. However, the deformations will be unacceptable. This is why membrane structures mostly have a doubly curved shape. It diminishes the deflections of the membrane. But, to be able to make a double curved shape out of flat sheets of material, the material must allow for considerable shear deformation. So, two structural features (membrane principle and double curvature) determine the two main properties of membrane material:
- Membrane material must only be able to transmit tension forces
- Membrane material must be able to allow for shear deformation.

This makes it clear why, for example, thin metal sheets are not so suitable for membrane structures. It is because they only allow for shear deformation under very high loading. Normally a woven material or a foil is used. The use of foil can be seen as a relatively new development. This explains why membrane structures are also often called fabric structures. Woven material is used both for synclastic and anticlastic structures, whereas foil is mostly used for synclastic structures, particularly air-inflated cushions.

Figures 1, 2 and 3 show successively a saddle shape and a synclastic shape, made out of flat pieces of metal sheet. The thin metal sheets are deformed into double curved membrane elements. By stressing the corners of the metal sheet, a saddle shape occurs (Fig.1). By over pressure the flat sheets are deformed into a synclastic shape (Fig.2 and 3). One can imagine the energy that is needed to make these models. Membrane materials should perform in such a way that the energy needed to obtain the final 3d curvature out of 2d planar elements is of an acceptable level.

As the most membrane structures are made from fabric, it seems reasonable to go into somewhat more detail on the fabric. In the next section there will be some explanation on how fabric is made. The most commonly used fibres are introduced, followed by a discussion on the fabrics available on the market today. The most commonly used foils are discussed afterwards.
2 THE FABRIC MATERIAL

Fabric material consists of woven threads (the weave) onto both sides of which a coating is applied (see figure 4). First the threads are discussed, followed by weaving methods. After that coatings are explained.

2.1 THREADS

A thread is built up out of fibres. There are natural fibres and chemical fibres. Natural fibres have a restricted length and are bound up in strands. These are the so-called spun fibres. Chemical fibres have a theoretically endless length and are called filaments. The cross-section of natural fibres is larger than 0.1mm, while chemical fibres can have smaller cross sections. The shape of the cross section is round for natural fibres but can have any shape in chemical fibres. For membrane structures it is best to have a yarn with a circular cross-section.

The mechanical properties of materials in the building industry are normally specified in N/mm². In technical textiles this is not common because it is not easy to determine the cross section of a very small fibre. Therefore it is usual to determine the weight of a fibre with a certain length. When the specific mass is known from the fibre, it is possible to determine an average cross-section of the material. This mass-per-length unit is indicated with Titer with the symbol Tex: 1 Tex weight in grams per 1000m lengths. In synthetic fibres it is common to use Decitex: 1 dTex= weight in grams per 10000m length [8].

A Polyester fibre, for example, with a Titer of 8.35 dTex has a weight of 8.35 grams at a length of 10000m. When the product is so small, it is very difficult to use it in industrial processes. Therefore it is spun into threads. One thread possibly consists of hundreds of fibres. When a thread has only one fibre, it is called monofil. Spun fibres need to be stabilised by twisting around the centre of the thread. Filaments don’t need this, but it facilitates the handling. The twisting influences the stress-strain behaviour of the threads. The more the thread is twisted the more the elasticity decreases compared to the elasticity of the fibre. With the adjustment of the twisting the mechanical properties of the thread can be determined precisely. The characterisation of a filament thread is according to the System Tex, where the number of fibres and twists are added. A thread, for example, which is termed 2200 dTex f 200 z 60 has a total Titer of 2200 dTex, made out of 200 fibres, the thread is twisted 60 times per meter in the z direction [8].

Another way of indicating the usefulness of a chemical fibre for tensile structures is the free tearing length. This describes the relationship between the weight and the tensile strength of the material. It is the length in km needed to tear the non-stretched thread under its own weight. For example, the free tearing length for steel is approximately 25 km, for cotton 48 km, for Polyamid 89 km, for polyester 94 km, for glass 140 km, for carbon fibre 153 km and for Aramid fibre 190 km [10].
2.2 THE FIBRES

There are several fibres that can be applied in membrane structures (see table 1). For each project it is necessary to consider which type of fabric can be used. Several fibres do have the potential to be applied; however the high costs may prevent a widespread utilisation.

### Table 1 Material properties of the base material of fabrics [7]

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>Tensile strength (N/mm²)</th>
<th>Tensile strain (%)</th>
<th>Elasticity (N/mm²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>1.5-1.54</td>
<td>350-700</td>
<td>6-15</td>
<td>4500-9000</td>
<td>Only for temporarily use of interest</td>
</tr>
<tr>
<td>Polyamide 6.6 (Nylon)</td>
<td>1.14</td>
<td>Until 1000</td>
<td>15-20</td>
<td>5000-6000</td>
<td>- When exposed to light only average resistance to ageing</td>
</tr>
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<td></td>
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<td></td>
<td>- Swelling when exposed to moisture</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Only of little importance in textile architecture</td>
</tr>
<tr>
<td>Polyester fibre (Trevira, Terylene, Dacron, Diolen)</td>
<td>1.38-1.41</td>
<td>1000-1300</td>
<td>10-18</td>
<td>10000-15000</td>
<td>- Widely spread, together with fiber glass a standard product in textile architecture</td>
</tr>
<tr>
<td>fiberglass</td>
<td>2.55</td>
<td>Until 3500</td>
<td>2-3.5</td>
<td>70000-90000</td>
<td>- When exposed to moisture, reduction of breaking strength</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Brittle fibres, therefore is spun into filaments of 3m diameter</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>- Together with Polyester a standard product in textile architecture</td>
</tr>
<tr>
<td>Aramid fibre (Kevlar, Arenka, Twaron)</td>
<td>1.45</td>
<td>Until 2700</td>
<td>2-4</td>
<td>130000-150000</td>
<td>- Special fibre for High tech products</td>
</tr>
<tr>
<td>Polytetrafluorethylen (Teflon, Hostafon, Polyflon, Toyoflon etc.)</td>
<td>2.1-2.3</td>
<td>160-380</td>
<td>13-32</td>
<td>700-4000</td>
<td>- High moisture resistance</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>- Remarkable anti adhesive</td>
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<td>- In air non-combustible</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>- Chemical inert</td>
</tr>
<tr>
<td>Carbon fibres (Celion, Carbolon, Sigrafil, Thorne)</td>
<td>1.7-2.0</td>
<td>2000-3000</td>
<td>&lt; 1</td>
<td>200000-500000</td>
<td>- Special fibres for high tech products</td>
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<td></td>
<td></td>
<td>- Very low expansion coefficient</td>
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<td>- Non-combustible</td>
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</table>

**COTTON FIBRE**

This type of organic fibre was used in membrane structures at the beginning of their development. Frei Otto used it for his early garden show structures and nowadays it is still applied with some rental tents. Due to its organic properties, the material is subject to fungi and moisture. It does have a high UV resistance. When used permanently it has an expected lifetime of about 4 to 5 years.

For growing the cotton, the crop is heavily sprayed with pesticides. Some of the cotton alternatives are the natural fibres such as hemp and flax. They are very sustainable, yielding a tremendous amount of fibres per acre. They are stronger than cotton and have almost as much UV resistance. These fibres should not be ignored when it comes to light-duty architectural applications [14]
**Polyamide 6.6 (Nylon)**
The nylon fibre has a poor resistance to UV light, swells in length when it gets wet, stretches considerably and is therefore of little importance for textile architecture. It is frequently applied in the sailing industry because of its low weight and high strength.

**Polyester**
Polyester, together with fibreglass, is the most common fibre in textile architecture and regarded as a standard product. The fibre has a good tensile strength and elasticity. Because of its considerable elongation before yield, the material is ‘forgiving’. It enables small corrections during installation. The mechanical properties of the material decrease by UV-light and there is ageing.

**Fiberglass**
The material from which fiberglass is made is of course glass. Threads are spun from glass which have a certain bending capacity. The fibreglass has a high tensile strength, but has brittle behavior and low elastic strain. Because of the brittleness the material needs to be handled carefully and needs very accurate manufacturing. Ageing exerts little influence on the material which has a tremendous impact on the expected lifetime of the structure. The tensile strength of the material decreases, however, when it is subjected to moisture. By blending quarry products (sand, kaolin, limestone, colemanite) at 1600°C, liquid glass is formed. The liquid is passed through micro-fine bushings and simultaneously cooled to produce glass fibre filaments. The filaments are drawn together into a strand, and coated to provide filament cohesion and protect the glass from abrasion [12]. For membrane structures, a continuous filament is normally used with a constant diameter of 3 micron. This provides the membrane with a good flexibility combined with a high tensile strength (it has greater specific tensile strength than steel wire of the same diameter, at a lower weight) [16]. If flexibility is not needed so much, another (larger) size of filament can be used, which reduces overall costs.

**Fluoropolymer Fibres**
Fluor Polymer fibres are known under several trade names including Teflon, Hostaflon, Polyflon, Toyoflon and, are normally made as monofil fibres. Amongst others, fibres are made from PTFE, PVDF and ETFE.

**Aramid fibre**
Aramid fibre is a man-made organic polymer (an aromatic polyamide) produced by spinning a solid fibre from a liquid chemical blend. The bright golden yellow filaments produced can have a range of properties, but all have high strength and low density giving very high specific strength. All grades have good resistance to impact, and lower modulus grades are used extensively in anti-ballistic applications. Compressive strength, however, is only similar to that of E glass. Although most commonly known under its DuPont trade name Kevlar®, there are now a number of suppliers of the fibre, most notably Akzo Nobel with ‘Twaron’. Each supplier offers several grades of Aramid with various combinations of modulus and surface finish to suit various applications. As well as the high strength properties, the fibres also offer good resistance to abrasion, and chemical and thermal degradation. However, the fibre can degrade slowly when exposed to ultraviolet light [12].
2.3 COMPOSITION OF THE BASE MATERIAL

Fabric that is normally used for membrane structures is built up out of a woven structural base material, to which a covering on both sides is applied to protect it from water and pollutants, the so-called coating. There are several ways to establish a coherent woven cloth. The basic method of weaving is called basket bond, where the weft threads pass the warp threads alternately above and below. There are many varieties possible, such as passing three warp threads underneath and one above. By doing this, many kinds of patterns occur such as is the case in the carpet industry. But for structural use only the basket bond and Panama bond are used for membrane structures (see figure 5). Panama bond indicates that the weave operation is done with more than one thread at a time. 12*12 Panama means that one cm of fabric contains twelve warp and twelve weft threads. On the other hand, it is also usual to say 2-2 Panama or 3-3 Panama which means that the weaving operation is done with, respectively, two and three threads at a time. Panama bond has a better mechanical behaviour than basket weave because of the multiple yarns used. Although it is quite common in use, the indication 12*12 Panama or 9*9 Panama does not say much about the strength of the material. You can have more threads per cm, but when they do not have a high strength, the resulting weave is not strong. In combination with the Titer of the material an indication of the strength is available.

![Basket bond and Panama bond](image)

2.4 AVAILABLE FABRICS

In table 1 the fibres from which fabric is woven are described (see figure 6). To create durable and watertight cloths most of the fibres need a coating on both sides. Moreover a coating is often used to create a smooth surface and thereby reduce the potential pollution area.

There are several coatings available. The most common ones are PVC coatings and Fluoropolymer coatings. Silicone coatings have made a comeback.

The coating is often used to weld the different parts of the membrane together. The adhesion of the coating to the fabric is an indication of the strength of the seams.
**COTTON FABRIC**

Cotton fabric is used mainly in the camping tent area for frame tents and caravan tents. As it is a non-coated weave, the fabric breathes, which creates a very pleasant atmosphere within the tent. It is often impregnated with a silicone spray to make it watertight. To improve the strength and durability of the material it is often blended with polyester. It then becomes possible to add, for example, a blackout layer and a dirt-resistant topcoat. It then loses its permeability.

- **Manufacturing:** Stitching.
- **Application:** Small scale temporary structures, retractable structures, not used frequently.

**PVC coating on Polyester cloth**

This type of coating is used mostly on Polyester fabric. It is either coated or laminated onto the cloth. Many different manufacturers provide such a material, which range from laminated fabrics for party rental tents, to heavy-coated fabrics for permanent (15-20 year replacement cycle) architectural installations. The fabric comes in numerous colours, and has four different top coatings:

- The basic top coating is an acrylic lacquer, a thin liquid coating applied to the surface of the PVC-coated fabric. Acrylics are generally known to have fair resistance to deterioration by UV light, so this thin coating is expected to erode and wear away relatively quickly, exposing the PVC and the fabric to the elements. As the plasticizers in the PVC migrate to the surface and attract and hold dirt, resulting discoloration of the fabric structure may be a sign that failure of the PVC coating is progressing [13].

- Weldable Fluoropolymer lacquer (PVDF, polyvinylidene fluoride) is also applied as a thin liquid to the surface of the PVC-coated fabric. The PVDF polymer has better resistance to UV light than acrylics. It is compounded with acrylics to reduce cost and make it heat sealable. [13]

- Non-weldable Fluoropolymer lacquer (PVDF). It has a much better resistance to soiling than the weldable one because it is less compounded with acrylics. To be able to weld it, the Fluoropolymer lacquer needs to be removed, or a butt-seam needs to be applied.

- PVF film. This is not a liquid topcoat; it is a film layer that is bonded to the vinyl fabric in the manufacturing process. It is in the same polymer family as Teflon and provides a clean, slippery surface that naturally resists dirt [13].

The material is considered a flame-retardant material: when the fire is removed, the fabric does not maintain the fire (self-extinguishing) and does not lead to the fall of burning droplets (see figure 7).
It is now possible to recycle the material. The coating is separated from the weave and both the Polyester and the PVC are available for further use. The process is called Texyloop [15].

- Manufacturing: High frequency welding is commonly used, hot air welding, hot-wedge welding, and stitching are also possible.
- Application: Temporary structures, permanent structures, retractable structures, small scale to large-scale structures. Commonly used.

**PVC, PTFE or Silicone coating on Aramid Weave**

Another interesting lightweight building material is Aramid fibre. Because of its high strength it is an interesting material for special applications. With a strain of 5 to 6% and a tensile strength of 24500 N/5cm it is by far the strongest synthetic membrane material. Because it is very sensible to UV-light, the coating needs to have a blackout layer to protect it fully from the UV. As a result there remains no translucency [10].

It was used for the Montreal Olympic stadium due to the high-tension forces that had to be met. At that time it was coated with PVC (see figure 8).

Another application is the use for air tubes. These high-pressure air tubes can take on the support function of a beam, an arch or a grid becoming a type of frame structure. The Aramid fibres are braided into curved forms and bonded to an inner urethane membrane to create seamless inflatable arches of approximately 30 psi. The Aramid fabric is enclosed with a PVC cover to protect the fibres from UV-degradation [1]. A drawback of the application of high-pressure tubes is the danger of explosion. The compressed air can expand with an enormous force.

Aramid weave coated with PTFE or Silicone is used in the conveyer belt industry.

- Manufacturing: Welding.
- Application: large scale structures, special applications. Only used when other materials are inadequate.
PTFE COATING ON FIBERGLASS WEAVE

Teflon coated fiberglass fabric is the most permanent of the coated architectural fabrics. First employed in 1973 for a roof at the La Verne College Student Centre in California (see figure 9), it has a lifetime of over 30 years. It can be used only for permanent applications and is not relocatable. The fabric is considered non-combustible and as such meets the most stringent building codes worldwide. Off the roll it has an oatmeal appearance which bleaches out to white after a couple of months in the sun. With translucency up to 25% it has been used in such projects as the Georgia dome, Denver Airport and the Millennium dome. Colours are possible, but not according to RAL numbers.

![Campus Centre, University of La Verne, 1973. The oldest commercial PTFE coated fiberglass membrane structure.](image)

The fabric has a topcoat of FEP to enhance impermeability, fungal resistance and weldability. The PTFE coating is built up out of several dispersions combined with fillers. The base coating is very important. It provides a solid anchorage to the glass fabric and is the base layer to the PTFE coats that will come on top. It also determines the flexibility characteristics of the finished coated product. Depending on the expected properties, different formulations can be used [16].

Teflon coated fiberglass is best used in large structures. Because the material does not stretch much, it is difficult to make small projects without wrinkles. Moreover, the fabric has a crackled effect, small folds occur during production, which remain visible when the fabric is close to the public.

- Manufacturing: Thermic welding with additive.
- Application: Permanent, mid-size and large scale structures. Frequently used especially when long lifespan is required.
Silicone Coating on Fiberglass Weave

Silicone coated fiberglass, which dates from 1981, has been used for Callaway Gardens in Georgia and the tensegrity domes for the Seoul Olympics. Silicone rubber is more flexible than Teflon, and fiberglass coated with it is less likely to be damaged during shipment and erection than fiberglass coated with Teflon. The greatest advantage, however, is that the fabric can be made very translucent, which is claimed to be as high as 25% translucency for the architectural membrane and 42% translucency for the thin liner material. With multiple layers of translucent membrane and glass fibre there can be both daylight illumination and very high heat retention. Silicone (Si) is one of the most abundant of the earth’s elements, and forms the basis of both the fiberglass threads of the fabric and the silicone rubber of the coating. This similarity in chemical structure allows the design of highly translucent fabrics, while the water protection provided by the silicone coating assures long life span for the fiberglass. With regard to cost and handling, Silicone coated fiberglass can be positioned somewhere between Teflon coated fiberglass and PVC coated Polyester.

There are several reasons why silicone has not been embraced by the industry. The first is that in some early attempts the silicone seams failed. Fortunately, new improved seaming technology has just been developed, allowing silicone-coated fabric to be welded in a process similar to that of PVC or PTFE (see figure 10 and 11, recent Si coated structure).

Secondly, silicone, as it is usually formulated, has a tendency to collect dirt. Like quartz, silicone carries an electrical charge that can attract debris. These then accumulate on its naturally tacky surface. However, a non-stick coating has recently been developed. Any particles attracted electrostatically simply wash off with rain. In fact, in humid conditions this is of little concern for the electrical charges in the air naturally neutralise this attraction. Perhaps the bottom line as to why silicone coating is not used, despite its superiority, is that it costs more to produce. However, that doesn’t mean it isn’t of good value. Although it may cost more up-front, silicone is actually less expensive for the consumer than PVC because it lasts several times longer [14].

- Manufacturing: Thermic welding with adhesive tape.
- Application: Temporary, retractable, permanent structures, mid-size and large scale. Comeback on the market. Very appropriate when high translucency is required.
PTFE FABRIC (COATED AND NON-COATED)

PTFE fabric is a material woven from expanded PTFE fibre. It is completely immune to UV light and resistant to acids, alkaline solutions and organic solvents over the entire useful temperature range. It feels like fine silk, is highly flexible and therefore is a very good material for retractable structures. For a long time it was only available as an open weave that did not offer protection against rain (see figure 12). Just recently introduced at the Techtextil 2003 is a coated PTFE fabric. So both weave and coating are from PTFE. The yarns are stronger than the former non-coated fabric and optimal weave layout is investigated.

The natural appearance of pure PTFE is water clear. When it is manipulated in processing it becomes white, just like water in the form of snow appears white. Translucency can be up to 40%. If less translucency is needed, it is possible to insert blocks that reduce it to 20%. The flexibility tests have proved that 50000 flex tests were survived by the material without leakage (according to the Newark flex test). Fluoropolymers in general and PTFE in particular are amongst the most non-combustible polymers known. The material fulfils several fire codes [17, 19].

• Manufacturing: Thermic welding, stitching.
• Application: The plain material without coating is very appropriate for retractable structures. The coated material is new on the market. Not so frequently used.

PVDF FABRIC

Also a relatively new fabric is a fabric made from PVDF yarns, optionally sealed with a Fluoropolymer coating or a Polyurethane coating. It is a material with optical properties which are unique in this field. It has a light transmission of up to 95% and scatters light up to 96%. There is no change in the spectrum of daylight or artificial light. Because of the high scattering rate there is hardly any shadowing effect (see figure 13, 14). It is available in clear and white. The white (opaque) version still has a high scattering rate (haze) but the translucency is up to 40%. It is a fire retardant material that extinguishes when the fire is removed. It has a very high weathering resistance, is colour-fast and can be recycled. It has a high resistance to acids, it is printable, does not smell, is easy to clean and nearly watertight (water column of 120 cm).
Because of the high translucency it is very appropriate for internal applications such as ceilings, walls and so on [18].

- Manufacturing: Thermic welding, stitching.
- Application: Interior applications where special light effects are required. New on the market. Has a high potential, also for exterior applications. Small scale structures.
3 FOILS

In some recent projects such as the Eden Project in Cornwall (see figure 15), a foil made out of ETFE (Ethyl Tetra Fluor Ethylene) was used as a membrane material. Foil development is already 20 years old. Recently it has received more interest from architects. One of the first structures built with it is Burgers Bush in the Netherlands.

Foil is mostly used as an air cushion; a small structural element which transfers the external loads to the boundaries of the panel, thence into the supporting structure which routes them down to the foundations. The foil is a more or less homogeneous material with a quite different mechanical behaviour compared to fabric material. Some major characteristics are:
- High tear strength
- Large strain (>200%)
- Good resistance against weather conditions
- High transparency, 95% per layer, high permeability of UV radiation
- Anti-adhesive which makes it self cleaning
- Chemically inert
- Good fire resistance (DIN 4102-B1)

Foil comes in different thicknesses ranging from 50µ to 250µ. The thickest foil has a tear strength of 500 N/5cm, which is more or less 1/6 of the strength of a type I polyester fabric (3000 N/5cm). This indicates that the span width of a foil element is considerably smaller than a corresponding fabric structure.

The great advantage of foil is the very low self-weight compared to glass and the free form architecture that is possible. So, in places where the translucency of a glass roof is needed, but also freedom in shape required, ETFE foil is a very good alternative.

- Manufacturing: Thermic welding
- Application: As a façade or roof element (air cushion), or as a small-scale tensile structure. Frequently used.

<table>
<thead>
<tr>
<th>Coating</th>
<th>Polyester fabric</th>
<th>Fiberglass fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top coating</td>
<td>PVC</td>
<td>PTFE</td>
</tr>
<tr>
<td>Ageing</td>
<td>Acrylic</td>
<td>&gt;30 years</td>
</tr>
<tr>
<td>Expected lifetime</td>
<td>8-10 years</td>
<td>Very good</td>
</tr>
<tr>
<td>Self-cleaning</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Transparency</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Fire-retardant</td>
<td>Average</td>
<td>Very good</td>
</tr>
<tr>
<td>Foldable</td>
<td>Very good</td>
<td>Bad</td>
</tr>
</tbody>
</table>

Table 2 Comparison of fabrics [4]
4 NEW DEVELOPMENTS

For a long time developments seemed to go slowly. It probably took a while to do the research and now, after this stretch of time, they have matured. As Silicone makes its comeback as a coating on Glassfiber for architectural fabrics, it is also said that research is being done on Silicone coating on Polyester weave by PVC/Polyester suppliers. A better non-combustibility and dirt resistance may be the objective.

Extensive research has been carried out on translucent insulation material to be able to reduce sound and heat loss. It is of course possible to enlarge the sound insulation and heat insulation for membrane structures by conventional means. A drawback of this is the loss of translucency, which is one of the main qualities of membrane structures. A material which increases heat and sound insulation adequately improves the possible applications of membrane structures [20].

The crossover of techniques from neighbouring industries has a high potential. Three-dimensional weaves offer large possibilities for membrane structures. Also, the use of composite lightweight elements constructed according to membrane principles turns the membrane industry in new directions (see figure 16).
A technique called ‘Cross-Ply’ enables the lamination of all kinds of fibres at different angels upon new or existing materials. In this way, existing materials can be strengthened or given a different appearance [21].

There will be many other interesting developments. To share them with others it is possible for them to be announced in the TensiNet Newsletter. Sharing knowledge creates new developments. New developments are an interesting part of life.

Fig. 16 Inflated mould for carbon fibre beam. The beam is a structural element of the membrane structure.
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There is no Material like Membrane Material

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