Materials for Membrane Structures

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The most prominent material for stressed membrane structures is obviously the fabric. It is prominently present, attracts much attention and looks very simple. To obtain this pleasant charisma there has been done a lot of research. The material is analysed and specific properties are defined and adapted. Properties like transparency, durability, fire retardance but also elasticity, strength.

In this paper the fabric is discussed to get a better understanding of those properties. The composition of the fabric is explained, followed by a discussion of the most common fabrics available today. Finally the structural behaviour of the fabric is discussed.

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 spin fibres. Chemical fibres theoretically have an endless length and are called filaments. The cross-section of natural fibres is smaller than 0.1mm, where chemical fibres can have larger 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/mm^2. 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 1 000m length. In synthetic fibres it is common to use decitex: 1 dtex = weight in grams per 10 000m length [7].

A Polyester fibre for example with a Titer of 8.35 dtex has a weight of 8.35 grams at a length of 10000 m. When the product is that small, it is very difficult to use it in industrial processes. Therefore it is spun into threads. One thread possibly consists out of hundreds of fibres. When a thread only has one fibre, it is called monofil. Spin fibres need to be stabilised by twisting around the centre of the thread. Filaments do not need it, 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 called 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 z direction [7].

There are several fibres that can be applied in membrane structures. 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 of it prevent a wide utilisation.

Cotton fibre

This type of fibre is the only organic fibre, which is being used in membrane structures. Frei Otto used it for his early garden show structures and nowadays it still is applied in some rental tents. As of its organic properties the material is subject to fungi and moisture. When used permanently it has an expected lifetime of about 4 years.

Polyamide 6.6 (Nylon)

The nylon fibre has a bad resistance against UV light, swells in length direction when it gets wet and is herewith of little importance for textile architecture. It is frequently applied in the sailing industry because of the little weight and high strength.

Polyester

Polyester fibre 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 to make small corrections during installation. The mechanical properties of the material decrease by sunlight and there is ageing.

Material	Density (g/cm^3)	Tensile strength (N/mm^2)	Tensile strain (%)	Elasticity (N/mM2)	Remarks
Cotton	1.5-1.54	350-700	6-15	4500 - 9000	Only for temporary use of interest
Polyamid 6.6 (Nylon)	1.14	Until 1 000	15-20	5000 - 6000	- When exposed to light only average resistance to ageing - Swelling when exposed to moisture - Only of little importance in textile architecture
Polyester fibre (Trevira, Teryiene, Dacron, Diolen)	1.38-1.41	1 000-1 300	10-18	10000 – 15000	- Widely spread, together with fibreglass a standard product in textile architecture
Fibreglass	2.55	Until 3500	2.0-3.5	70000 - 90000	- When exposed to moisture, reduction of breaking strength - Brittle fibres, therefore is spun into filaments of 3 µm diameter - Together with Polyester a standard product in textile architecture
Aramid fibre (Kevlar, Arenka Twaron)	1.45	Until 2700	2-4	130000 - 150000	- Special fibre for high-tech products
Polytetrafluor-ethylen (Teflon, Hostaflon Polyflon, Toyoflon etc.)	2.1-2.3	160-380	13-32	700 - 4000	- High moisture resistance - Remarkable anti adhesive - In air non-combustible - Chemical inert
Carbon fibres (Celion, Carbolon, Sigrafil, Thornel)	1.7-2.0	2000-3000	< 1	200000 - 500000	- Special fibres for high-tech products - Very low expansion coefficient - Non-combustible

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

Fibreglass

The material where fibreglass is made of is of course glass, where threads are spun from, which have a certain bending capacity. The fibreglass has a high tensile strength, but remains brittle and has 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 what has a tremendous impact on the expected lifetime of the structure. But the tensile strength of the material decreases when it is subjected to moisture.

Aramid fibre

This is a relative new type of fibre, discovered simultaneously by Akzo (Twaron fibre) and DuPont (Keviar fibre). The material has a high tensile strength and is chemically resistant. A drawback is the low elastic strain and the bad resistance against high temperature and UV-light

Composition of the base material

Fabric that is used normally for membrane structures is built up out of a woven structural base material, which has a covering on both sides 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 alternating above and underneath. There are a lot of varieties possible, like passing three warp threads underneath and one above.

Fig. 1 Basket bond (left) and Panama bond

Doing this, all kinds of patterns occur like is done in the carpet industry. But for structural use this it is not very sufficient and therefore only the basket bond and