SOFTENING THE HABITATS
SUSTAINABLE INNOVATION IN MINIMAL MASS STRUCTURES AND LIGHTWEIGHT ARCHITECTURES

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Development and testing of a new glass fibre reinforced fluoropolymer membrane

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Abstract

Coated textiles for permanent membrane structures rely on very few products, the predominant membranes are polyvinylchloride (PVC) coated and polytetrafluoroethylene (PTFE) coated fabrics. These products have been adopted by the market due to their versatility and price/performance ratio. PVC and PTFE are limited with regards to advanced properties that have been intensively developed in other construction materials in recent years.

A laminated membrane that consists of PVDF films reinforced with glass fibre mesh (called Fluoscrim™) was developed to explore additional solutions for permanent architectural membrane structures. This newly produced membrane has been tested according to membrane industry standard test methods and other internal test procedures to prove its potential as a permanent membrane for tensile architecture.

Keywords: membrane, tensile architecture, translucency, glass fibre mesh, fluoropolymers, development, testing, manufacturing.

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1. Introduction

The tensile architecture community have expressed enthusiasm over the decades for the dramatic architectural and engineered forms they developed since the pioneering work in the 50’s.

Today there is still enthusiasm for the elegance of minimalistic forms and widespan fabric structures. These constructions are capable of softly enclosing large surface areas only by slender cables, mast supports and a membrane only a millimeter thick. Indeed, unique shapes are achievable with membranes; more importantly the ability to harness natural light creates a unique sense of well-being.

Key benefits of architectural membranes are now counterbalanced by accelerating demands for advanced building materials that combine improved environmental efficiency with flatter designs, which are not ideal for membrane structures. Furthermore, tensile architecture has been dominated by polyvinylchloride (PVC) coated fabrics, polytetrafluoroethylene (PTFE) coated fabrics and ethylene tetrafluoroethylene (ETFE) foils to develop permanent prestressed membrane structures.

In order to develop further, the membrane for tensile architecture is going through the transition of free form material to a system solution that must prove its efficiency and competitiveness in developing cutting edge performance and ecological building envelopes.

As technical textile innovators, we acknowledge that a material evolution is urgently needed. A proper evolution must be envisioned as a component of a system solution to rejuvenate the attractiveness of tensile architecture. On one hand we must deal with the limited market size and its specificities; and on the other, we can observe that the integration of advanced features in such highly customized, thin skin structures remain a challenge for the entire industry supply chain. As a result, the general lack of deep collaboration combined with limited economical impact should make one accept that we can mainly be innovators, benefiting from ideas and materials created for adjacent industries that have the budget and the means to invent new ones.

With the previous assessments taken into consideration, the goal of this work is to develop and evaluate the performance of a new kind of glass fibre reinforced fluoropolymer membrane for tensile architecture construction. This material represents a “range extender” combining a few advanced features that can be beneficial for this specialized industry.

2. Tensile architecture membranes for permanent buildings: preamble

To conduct the development of new membrane materials, we mapped first the accepted tensile architecture products. We can rapidly notice that the industry is mainly using PVC coated fabrics, PTFE coated fabrics and ETFE foils to develop permanent prestressed membrane structures. [1,2]

Noteworthy, from the business point of view, one can notice that there is not always early and intensive collaboration within the protagonists of the project (from the owners, designers, engineers, material suppliers, installers and the service team responsible for the maintenance of the structure). Therefore, the introduction of a new material can be successfully foreseen only with intensive and trustworthy collaboration with all the project's partners not only in the preparation phase but also long after the material has been installed.

Today, a key challenge which must kept in mind is the overall environmental impact of developing a new object. To be proper stewards to the environment we need to assess, understand and reduce impact that this new item will have on the world around us. This mindset is rather new in the field, twenty years ago the environment was not the main concern for professionals. Today one can consider that by design, the object is not only faulty when it does not perform but also when its eco-efficiency is poor.

3. Material development

For this development we decided, after analyses and interviews of the tensile community, to investigate the development of a reinforced ETFE material in order to create a membrane material at the crossroads of PTFE coated membranes and ETFE foils.

Two similar products were appearing on the marketplace during the development of our first prototypes: PTFE and THV (terpolymer of Tetrafluoroethylene, Hexafluoropropylene and Vinylidene) films or foils sandwiching glass fibre meshes. There are very few groups to work on such similar product concepts.

Internally, a vast set of prototypes was executed from a broad range of building blocks and production techniques. They were characterized following an internal stage gate method:

- Material properties
- Material availability
- Prototype physical performances and aspect at lab scale
- Up-scalability & recyclability perspectives
- Validation of physical performance at production scale
- Product placement in the perspective of commercialization
- Advanced physical performance and final validation.

It is not the intention to explain in detail the different properties and iterations being made but highlighting some technical issues that were key during the development stage,

a) Membrane ageing under artificial accelerated weathering tests
b) Confectioning of the membrane materials using high frequency (HF) welding techniques
c) Biaxial properties of the membrane

a) Membrane ageing under artificial accelerated weathering tests

The configuration of the equipment and this specific method for tested material is made to assess material's chemical stability through artificial weathering test.

Artificial weathering is aimed to reproduce natural weather conditions an architectural membrane will endure throughout its useful lifespan. Testing simulates the main degradation factors of temperature, UV, humidity and a combination of mentioned. Secondary degradation factors like microorganisms, pollution and corrosive gases were not the subject of these studies and we realize they can take a predominant role in some areas.

In QUV artificial weathering, the aim is to assess the coating stability against cycles of high temperature and high UVA exposure together with water condensation cycles.

The time the material is stressed and the temperature during ultraviolet (UV) and water stresses are the primary variables in natural weathering. The scope of this study is limited by defining weathering as degradation which occurs when a material is exposed to universal stresses of ultraviolet energy in sunlight, water as rain or dew, and temperature. It is recognized that there are other stresses from salt water, biological and air pollution. These weathering stresses that occur in some environments are not evaluated in this test method. Suggested limits and methods of operating the apparatus have been recently standardized and published in ASTM G-53-77: Recommended Practice for Operating Light and Water Exposure Apparatus (Fluorescent UV-Condensation Type) of Non-Metallic Materials.

The test equipment consists of a QUV accelerated weathering tester equipped with UVA-340 lamps (Figure 1) and solar eye which measure and control the emitted radiations that is received by the samples.

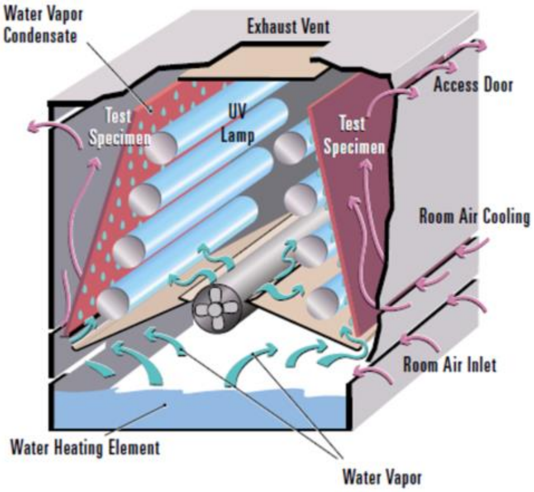


Figure 1: Scheme of a QUV accelerated weathering tester (scheme extracted from the Weathering testing guidebook from Atlas Corporation).

Test conditions are calibrated following the Q-lab Technical Bulletin LU-8160, and for correlation of laboratory to natural weathering, please refer to Q-lab Technical Bulletin LU-0824. In summary, we used UVA 340nm lamps with a normal irradiance of 0.68W/m² in order to mimic closely the UV irradiation of the membrane at the surface of earth (Figure 2).

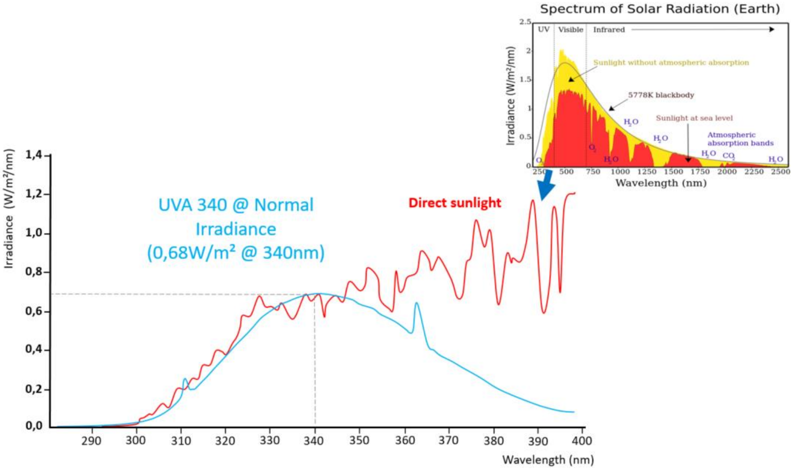


Figure 2: UVA 340 lamp irradiance and direct sunlight comparison calibration.

Different ageing stresses exist through the profile of a material as water is absorbed and desorbed (figure 3), these are mimicked in the QUV test cycle described in table 1.

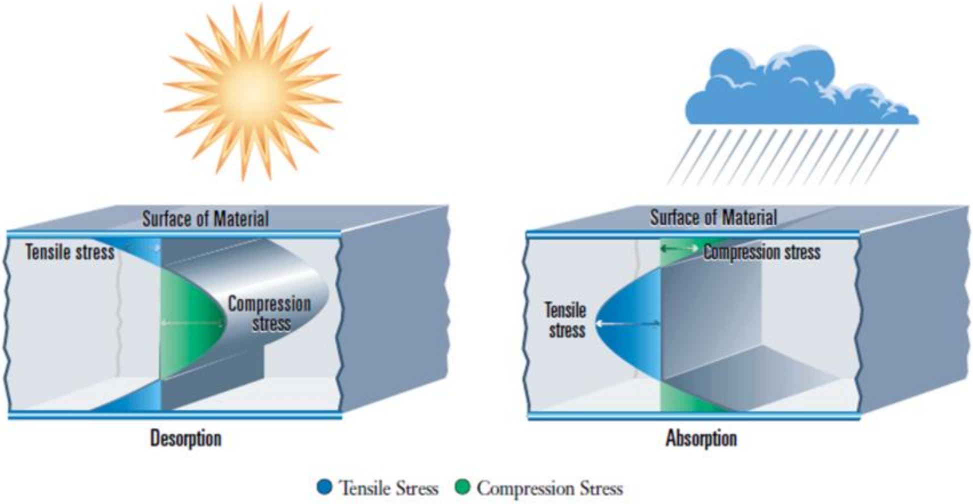


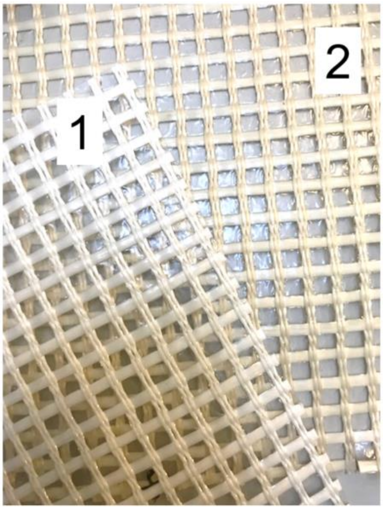
Figure 3: Representation of material stresses due to absorption and desorption of water (scheme extracted from the Weathering testing guidebook from Atlas Corporation).

Step	Function	Irradiance (W/m²) @ 340nm	Temperature (°C)	Time (hh:mm)
1	UV irradiation	0,68	60	04:00
2	condensation	0	40	04:00
3	repeat	Go to step 1		

Table 1: Test cycles used in the QUV testing protocol

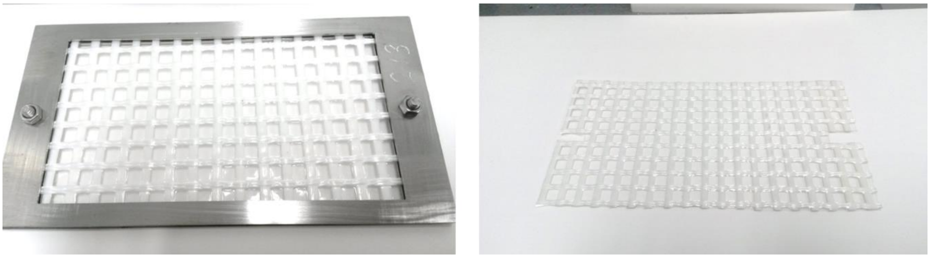
As a preliminary test, the Fluoscrim™ membrane was exposed to 4000h of the above calibrated cycles in order to provide an assessment of the UV, temperature and water absorption and desorption ageing.

Inspection of the material indicated no physical damage of the test sample with remarkable whitening of the fabric under UV exposure (Picture 1).



Picture 1: Inspection of the 4000h test piece (1) against the reference (unexposed) material (2)

Additionally a weathering test under Florida weather conditions is running. So far, after 100 weeks, the results obtained are in line with laboratory conditions picture 2.



Picture 2: Inspection of the Fluoscrim™ membrane test piece after 100 weeks in Florida weather conditions.

From these preliminary tests, we ensured that the developed Fluoscrim™ laminate has promising stability to external simulated and real UV conditions. Compared to other membrane materials being tested in this simulation, Fluoscrim™ laminate is performing as the most stable membrane available.

The tests are still running in order to investigate the impact of long stress exposures to the investigated conditions.

We also understand that the above tested conditions are not representative of all climates nor outdoor conditions but are giving the first positive indications of material stability against temperature, UV and water condensation cycles. These studies are corroborated with jungle and temperature stability tests. These tests simulate additional intense temperature and humidity stress conditions.

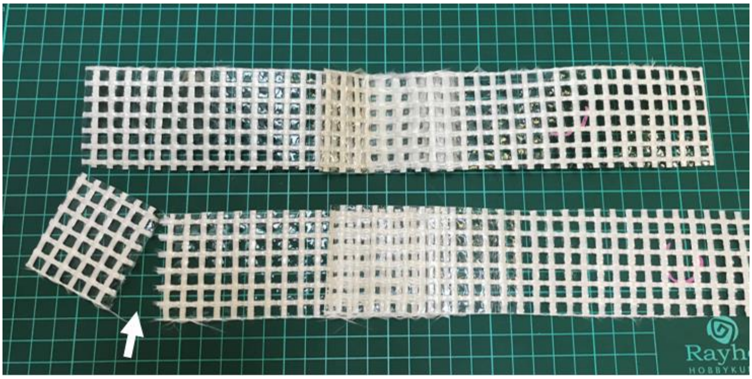
b) Confectioning of the membrane materials using high frequency (HF) welding techniques

An interesting feature that we were eager to develop with this material was the possibility to offer to the market the possibility to use HF welding techniques to fabricate structures. Contrary to PTFE or ETFE membranes that requires the fabricators to equip with additional specific equipment, the developed Fluoscrim™ membrane material is aimed to be confectioned using standard HF welding machinery used for PVC coated PES fabrics.

In the early development stage, the material selection allowed us to envision this unique feature for a glass fibre reinforced fluoropolymer laminate. The HF welding properties of the materials were not only developed to allow the welding of the material on itself but also to other types of architectural materials (mainly PVC coated PES fabrics) confectioned using the same equipment.

The optimal machine parameters for welding the Fluoscrim™ on itself need to be preliminarily tested by the operator, and so far, the numerous tests done at third party facilities were successful using HF conditions close to the ones usually used for tensile architecture PVC fabrics.

The obtained welds were tested following the EN ISO 1421:2016 (Rubber or plastics coated fabrics- determination of tensile strength and elongation at break) and EN ISO 2411:2017 procedure (Rubber or plastics-coated fabrics- determination of coating adhesion) at different temperature as proposed in the JRC's science and policy report number 100166.[3] Noteworthy testing such glass fibres materials requires adaptation of the clamp system test equipment to avoid misleading results where the glass fibres will break at the clamp end tip (picture 3).



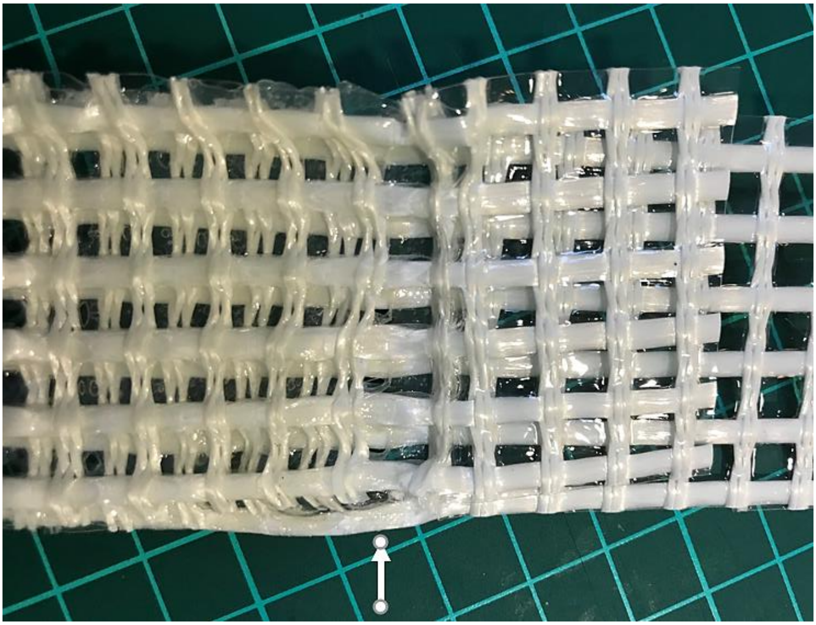
Picture 3: Welded Fluoscrim™ pieces tested under EN ISO 1421 protocol. The bottom sample shows a failure due to the use of an inappropriate clamp system.

The weld and adhesion performances were tested for both mesh directions and for each condition with a minimum 5 sample pieces taken from 2 different production batches. The table 2 displays the obtained test results.

EN ISO 1421 "Seam's tensile strength at break"						
Temp.	Direction	Weld width (cm)	Min (N/5cm)	Max (N/5cm)	Average (N/5cm)	Observations
20°C	Warp	6cm	4240	5560	4670	Avg.elong. at break 4.9%
	Weft		4180	5430	4750	Avg elong. At break 5.0%
	Weft	5cm	3110	3755	3600	Creep at weld
	Weft	4cm	2516	2973	2733	Creep at weld
70°C	Warp	5cm	1860	2730	2230	Creep at weld
	Weft		2040	2670	2440	Creep at weld

EN 2411 "coating adhesion"					
Temp.	Direction	Min (N/5cm)	Max (N/5cm)	Average (N/5cm)	Observations
20°C	Warp	172	248	224	
	Weft	183	274	238	

Table 2: Test results weld seams strength and coating adhesion for Fluoscrim™ on itself

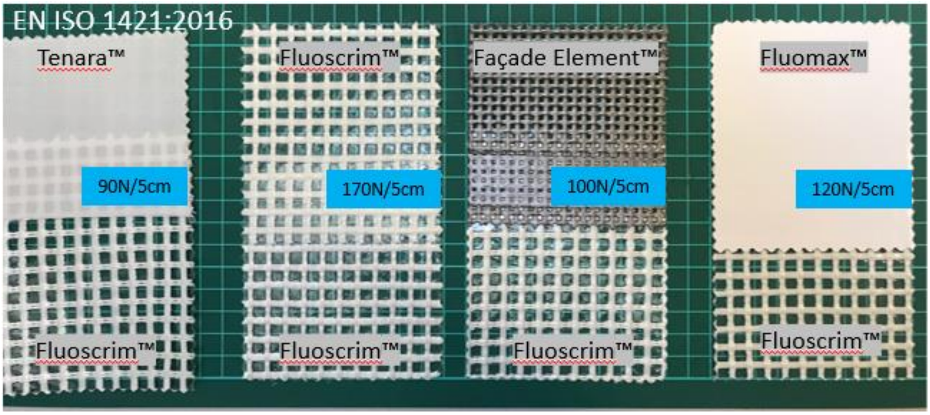


Picture 4: Illustration of the “creep at weld” for the test EN ISO 1421 at 70°C on Fluoscrim™ sample

For the EN ISO 1421 tests, the seam width of 6cm resulted in the glass fibre breakage, this leads us to think that the optimum seams width in our welding conditions is 6cm. Smaller seam widths (<6cm) or higher temperature resulted in the sliding of the mesh at the seams (like exemplified in picture 4). We believe the creep is mainly is due to the e-modulus to temperature value of the film’s resin.

For the EN ISO 2411 tests, we can observe that the complexation of the films on the glass mesh offers a reliable and consistent adhesion. The adhesion consistency is best achieved when using soft electrodes during the welding.

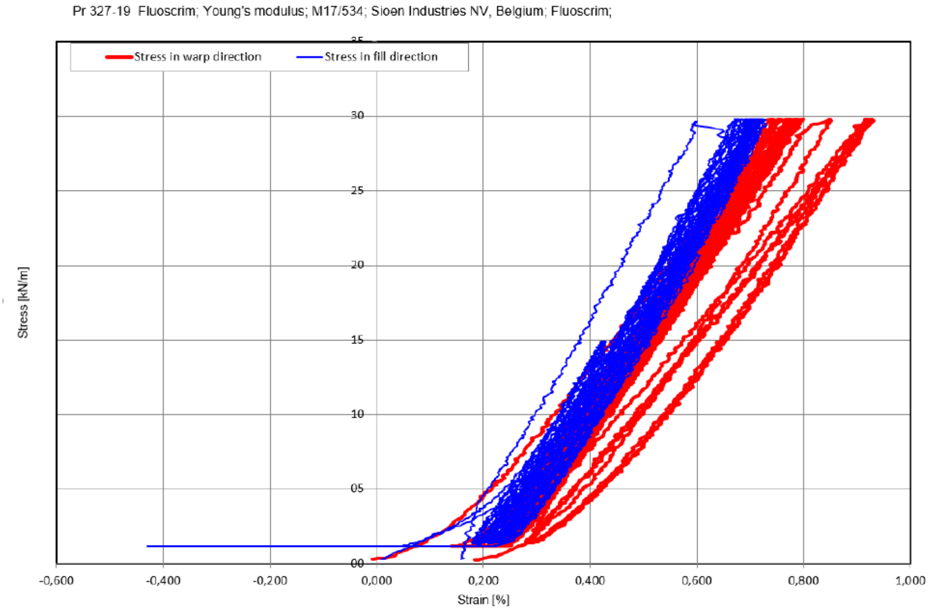
We conducted similar preliminary studies to weld the Fluoscrim™ with other membrane materials. We were successful to weld the Fluoscrim™ with PVC coated PES membranes, results showed best adhesion for PVC coated membranes with PVDF topcoats (such as Fluomax™ and Fluo^{2}max™). Tenara™ coated membranes were also welded effectively but this time using an adhesion tape film made of FEP or PVDF. Values obtained for different materials are preliminarily indicated in picture 5.



Picture 5: 2cm width welding results with different materials under EN ISO 1421 test method

c) Biaxial behaviour of the membrane

Another important point for us during the development was to create a material that has predictable and reliable elastic behaviour in warp and weft directions. Internal weaving knowledge lead us to the design of a leno weave mesh with reliable 4500N/5cm tensile strength in warp and weft directions. The developed Fluoscrim™ was tested following the MSAJ Biaxial test procedure. As a result the membrane showed high stiffness and very close e-modulus results as showed in the graph 1.



Graph 1: Stress = f(strain) under the MSAJ biaxial procedure for the Fluoscrim™ membrane

4. Conclusion and perspectives

As a conclusion, we believe the preliminary test results give promising information related to the use of Fluoscrim™ in projects where long-term high translucency wide span structures are envisioned. This material is now available for use in tensile architecture projects. Some advanced properties are currently being optimized for a standard product offering.

One important perspective to Fluoscrim™ material is the ability to be recycled thanks to material separation. Recycling and the completion of the life cycle analysis will surely provide insight, leading us to reduce our production and logistic processes. These insights are needed to bring a more sustainable approach on material development for the tensile architecture construction industry.

5. Acknowledgements

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