A New Membrane Material for Fabric Structures
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Introduction

Over the years many membrane materials have been used in the construction of protective structures. These membranes have been made from natural materials, such as animal skins or woven cotton, and also from man-made materials. The market has continually demanded, and the industry has endeavored to supply, materials that last longer, look better, are easier to work with, and are safer.

In this paper I will disclose a new membrane material that Gore is introducing at the 2003 Techtextil, which represents a significant advancement over materials previously available. I'll explain the driving forces for the development of this material, its construction and physical properties, and will also discuss initial projects.

Background

Today there are two dominant types of fabrics that are widely used in building fabric structures; they are PTFE-coated woven fiberglass, and PVC-coated woven polyester. Each of these materials takes advantage of certain physical properties, and combines them to give optimum value and performance for the user. Experience has shown that no materials are perfect for all applications. As a result material properties are matched to the performance requirements and budgetary constraints of the project.

PTFE-coated fiberglass is known for its long life, high tensile strength, non-combustibility, and self-cleaning nature. Close attention must be paid while handling this material as a crease can cause damage to the glass fibers, and sometimes to the coating itself, rendering the fabric much weaker and potentially susceptible to coating failure. Visible light transmission is typically 20% for lighter weight fabrics and 10% for heavier fabrics. A sun-bleaching process that occurs over several months ‘bleaches’ the beige colored fabric to its typical white color. Hot bar welding is the typical method used for joining sections. PTFE-fiberglass is best suited for permanent installations.

PVC-coated polyester is known for flexibility, and lower cost but shorter useable life as compared to PTFE-fiberglass. The PVC coatings are generally thick enough to protect the polyester fiber from the sun’s damaging UV rays. Fluoropolymer topcoats such as PVF films and PVDF coatings release dirt more readily than PVC alone. Flexing while handling will not damage the structural component of the membrane, yet popular versions with dirt-release coatings or films do not lend themselves to repeated flexing due to cracking of the top coat or film delamination. Flame retardant versions are widely available. Visible light transmission is normally in the 10% range, and while white seems to be the dominant color used, other colors are available. High frequency (RF) welding is the dominant joining technology. PVC-polyester is suited for permanent, temporary, and deployable structures.
Gore has marketed PTFE yarns, sewing thread and fabrics woven of these yarns to the fabric structure industry as TENARA® fabric, sewing thread and fiber. TENARA textile products have a significant advantage in outdoor applications in that UV radiation does not weaken it, nor do most chemicals. A famous project that uses TENARA Fabric is the inner courtyard of the Prophet’s Holy Mosque in Medina, Saudi Arabia. (See Photo 1.) Twelve retractable umbrellas, each 17 x 18 meters, shade worshippers during the day and are retracted at night to allow the courtyard to cool by radiating energy into the desert sky. The umbrellas have been in continuous use since 1992, and show no signs of deterioration. While the fabric used in this application is tightly woven, and will shed water, it is not considered waterproof. As this was installed in a desert location, waterproofness was not considered a critical requirement of the structure. Most locations typically have the requirement to provide protection from the full range of environmental elements, especially rain, and so Gore has been asked over the years if we could provide a waterproof version of our TENARA fabric.

![Photo 1. – Medina, Saudi Arabia](image)

When we investigated the application needs thoroughly, we found that the combination of requirements for this product would be very challenging to achieve. The fabric would have to be strong, waterproof, flexible, non-combustible, highly light transmissive, self-cleaning, be easily seamed, and maintain these properties for a very long time, at least fifteen years. Even with all of these properties, it must be affordable.

Our new GORE™ TENARA® architectural fabric is the culmination of several years of research and development, and meets the structural and market demands of an architectural fabric. I will now explain the construction of this new material.
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Product Development

The backbone of this product is Gore’s high strength expanded PTFE yarn that was initially introduced at Techtextil 2001. It is 50% stronger than our standard yarn and the strongest PTFE yarn available anywhere. Using this high strength yarn, we experimented with numerous weave designs to balance the needs of strength and flexibility.

Once the optimum weave designs were established, a proprietary coating system was developed to provide waterproofness, even when subjected to aggressive flexing, tensioning and weathering. Both sides of the fabric are coated for increased durability. This coating system results in an architectural fabric construction that is all-fluoropolymer, and has excellent flammability characteristics. Because the structural fibers are inherently unaffected by solar UV radiation, there is no need for the coating to block sunlight. Therefore, light transmission of up to 40% is available in GORE TENARA architectural fabric.

In summary, new GORE TENARA Architectural Fabric by Gore is 100% fluoropolymer with a backbone of Gore High Tenacity ePTFE yarn. To date we have developed two versions of this product, a Type 1 (3000 N/5cm) and a Type 2 (4000 N/5cm). Each of these types is available in 20% and 40% nominal visible light transmission options. Patents covering these products are now pending.

Below is a chart that summarizes some of the physical properties of this new material:

<table>
<thead>
<tr>
<th></th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g/m**2)</td>
<td>630</td>
<td>830</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0.38</td>
<td>0.43</td>
</tr>
<tr>
<td>Width (meters)</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Strip Tensile (N/5cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ASTM D4851)</td>
<td>3000 Warp</td>
<td>4200 Warp</td>
</tr>
<tr>
<td></td>
<td>2900 Fill</td>
<td>4000 Fill</td>
</tr>
<tr>
<td>Trapezoidal Tear (N)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ASTM D4851)</td>
<td>818 Warp</td>
<td>925 Warp</td>
</tr>
<tr>
<td></td>
<td>854 Fill</td>
<td>925 Fill</td>
</tr>
<tr>
<td>Visible Light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission (%)</td>
<td>38 or 19</td>
<td>38 or 19</td>
</tr>
<tr>
<td>(ASTM E903)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Tear Strength**

I would like to highlight several properties unique to this fabric. The tear strength as measured by the Trapezoidal Tear method is comparatively high, about 800 to 900 Newtons. This is largely due to the ability of the PTFE yarn to shift within the composite and distribute the tearing load. Comparable values for PTFE-fiberglass are 200 to 300 Newtons, and for PVC-polyester are 300 to 400 Newtons. Since tearing is a potential failure mode, it follows that a fabric more resistant to tearing would be desired, and potentially could increase the ‘safety factor’ associated in a tensioned fabric structure.

The chart of Figure 1 compares the tear and strip tensile strengths (as measured by ASTM D4851) for the new GORE TENARA fabric and published values for representative samples of PVC-polyester and PTFE-fiberglass. While the strip tensile strengths of all specimens are similar, the chart illustrates that the tear strength of the GORE TENARA fabric is significantly higher than the comparative samples.

![Comparison of Tear Strength to Strip Tensile](chart.png)

**Figure 1.**
Bi-Axial Properties

Bi-axial tensile testing has been performed on both GORE TENARA Type 1 and Type 2 fabrics. In general, the warp is somewhat stiffer than the fill, resulting in warp compensation factors of about 1% and in the fill approximately 3%.

Light Transmission/Colors

The natural appearance of pure, fully dense PTFE is water clear. When it is manipulated in processing, microscopic voids are created causing it to appear white, much in the same way that water in the form of snow appears white. The fluoropolymer coatings used are also naturally clear, so it makes sense that the composite is translucent and as such transmits nearly 40% of the visible spectrum. This high light transmission is desired if the aim is to give a very open and airy feeling. However, if additional light blocking is desired, this product can be formulated to provide more shading. A version that provides 20% nominal visible light transmission has been developed and it is possible to block even more if needed by the market.

Colors other than translucent or white are possible with this system. For example a sky-blue has been formulated using a UV-stable pigment for a project in the United States. Other colors can be produced if there is a demand.

Flex Durability

In order for this material to be used for temporary and retractable structures, it must retain its waterproofness even after repeated flexing. The test we used to investigate this behavior is called the Newark Flex Test. In this test, an 83 x 108 mm rectangle of fabric is rolled into a cylindrical shape, mounted on the tester and the cylinder is effectively crushed by the machine at a rate of nine times per second. At the conclusion of the test the sample is removed and tested for waterproofness by subjecting it to a hydrostatic pressure of 78 millibars for three minutes. If no water appears on the dry side of the specimen, it has passed the test.

Our original goal was to develop a material that survived at least 20,000 flex cycles without leakage. We have exceeded this goal, and our current generation will survive over 50,000 cycles. This result indicates that this fabric is ideal for a structure that undergoes repeated set-up and take-down, or for retractable structures that are frequently opened and closed.

Flammability

Non-combustibility is measured in many ways. There are numerous tests to determine the suitability of a material dependent upon the location, structure type, and use. Fluoropolymers in general, and in particular PTFE, are among the most non-combustible polymers known. All of the components used in this product are rated UL V-0. To date this new fabric has been tested against the vertical flame test (ASTM D6413/FTM191-
5903) and exhibited approximately one second afterflame and no measurable afterglow with no observed melting or dripping. Testing according to numerous International standards is underway.

Aging

Fluoropolymers are also naturally tolerant of terrestrial solar radiation exposure. PTFE comprises the structural component of GORE TENARA architectural fabric and does not lose strength when subject to solar UV radiation. The fluoropolymers used to impart waterproofness have been subjected to 3000 hours of 1 watt/m**2/nanometer in a QUV weatherometer, and have shown no signs of aging such as yellowing or stiffening. Test fabrics have been out in the weather for about eighteen months, and have remained clean and white due to the fabric’s dirt release characteristics.

Seaming

While all that has been described above is important, it would be of limited value if the fabric could not be bonded to itself with strong, waterproof seams. This material is straightforward to seam with equipment used to weld PTFE-fiberglass. The steps to seam are as follows:

1. Prepare edges to be joined by lightly abrading seam area with a 180 grit abrasive media
2. Lay seam tape on seam area of one fabric edge, it can be tacked into place with a small hot iron
3. Lay other fabric edge on top of seam tape, it can also be tacked into place if desired
4. Apply heat and pressure to produce the welded seam:
   - Typical condition is 230°C (446°F) for 45 seconds if heating from one side, or 190°C (374°F) for 30 seconds if heated top and bottom, pressure 35 to 70 kilopascals (5 to 10 psi) on the material
   - The welding conditions will vary with the type and capacity of the equipment used. Hot bars must either be very flat for equal distribution of heat and pressure, or one of the surfaces should be conformable to compensate for irregularities in the equipment and fabric

A 50 mm weld overlap is recommended for the Type 1 fabric, and a 62 mm weld overlap is recommended for the Type 2 fabric. Weld strength at room temperature is typically 90% to 95% of the fabric strength. At elevated temperature (70°C or 158°F) the weld strength is typically 60% to 70% of the room temperature fabric strength.

In situations where sewing is required, GORE TENARA sewing thread should be used as it will not degrade due to exposure to the elements.
Projects

As this is a relatively new material, we have just begun to gain real world experience through initial projects. To obtain a very basic understanding of appearance and performance, we first built three very modest canopies; 2 permanent and 1 retractable. They are shown in the photos 2, 3, and 4 below. While these projects are quite small, they have produced good information relative to fabrication techniques and the self-cleaning nature of the fabric.

![Photo 2. – Entrance Canopy](image)

![Photo 3. – Rigid Canopy](image)
A more ambitious project was constructed in April of 2002. This first tensile structure was built using the Type 1 material in Flagstaff, Arizona, USA. (See Photo 5.) The 5 meter x 17 meter membrane covers the entrance ramp to a commercial building. Eide Industries of Cerritos, California, USA fabricated and installed this project. After one year the fabric remains tight and clean.
The first large retractable structure was installed in November 2002 at the Villa D’Este outside of Rome. This 10 meter x 30 meter project used the Type 2 material to cover an outdoor terrace. It was designed by SL Rasch of Germany and fabricated by Canobbio of Italy. In this structure the flexibility of the fabric is a critical property, as this roof will be cycled many times over its life. This roof system is suspended by steel cables and can be retracted to allow full sunlight on the terrace. When the roof is extended, the high light transmission of the membrane creates a very open environment, allowing about 40% of the ambient light into the covered space. (See Photo 6, courtesy of SL Rasch)

Two additional projects are underway and are scheduled for completion in the spring of 2003. The first is an 8 meter diameter permanent umbrella which is designed and fabricated by Sopers of Ontario, Canada. Type 2 translucent fabric was used in the fabrication of the membrane.

The second project is an entrance canopy for a regional airport in Scottsdale, Arizona, USA. The sky-blue Type 2 material has been produced for this project. World Cover of Oklahoma, USA, will perform the fabrication and installation.
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Summary

The new waterproof and flexible GORE TENARA Architectural fabric offers a unique set of capabilities previously unattainable in an architectural membrane fabric. It will enable longer life membranes for retractable structures, and easy to fabricate, highly light transmissive membranes for permanent structures. This unique combination of aesthetics and durability will enable a new range of design opportunities for fabric structures.

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