HATERIALS FOR HIGH PERFORMANCE STRUCTURES

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, Architectural fabric structures are well established as a dynamic form of construction, uniquely suited to particular building applications. Less well known, are the performance criteria which must be met by fabrics in order to assure long life and good performance. This paper discusses these criteria in the light of recent developments and industry standards in relation to usage on high performance structures.

INTRODUCTION

The last decade has seen a significant growth in the use of fabrics as structural materials. However, while designers and specifiers have developed a strong awareness of the structural concept, in many cases the importance of the fabric performance characteristics has been neglected.

The performance requirements for architectural membranes can be split into three general areas:

1) SHORT TERM PROPERTIES

Generally these are mechanical properties of the base fabric required to withstand environmental loadings of short duration eg. wind, snow, impacts, erection loads. Properties include:

Tensile Strength
Tear Strength
Resistance to Tear Propagation
Puncture Resistance

2) LONG TERM PROPERTIES

Generally these are properties of the coating and coating/base fabric interface, as well as fire performance properties of the total fabric. These properties include:

Weathering & U.V. Performance
Adhesion of Coating
High Temperature Seam Strength
Wicking Performance
Abrasion Resistance
Cold Weather Flexibility
Dimensional Stability
Cleanability
Fire Behaviour
Repairability

3) FABRICATION REQUIREMENTS, ECONOMICS

The third area concerns the ability of the material to be fabricated into practical membrane components. Their properties include:

Dimensional Stability of Base Fabric
Weldability of the Coating
Resistance to Fold Damage

TEST PROCEDURES

In order to evaluate any membrane material, a set of comparable and valid test results is necessary. With regard to Short Term Properties, the following are relevant;

TENSILE STRENGTH

Strip Tensile: The breaking force of a uniaxially loaded strip of fabric of set width. Normally quoted in N/mm, KN/m, N/50cm, LBF/in. Used for design to resist environmental loading, chiefly wind and snow.

Grab Tensile: The breaking force of a uniaxially loaded strip 100mm wide, loaded through 25mm wide jaws. This measures the load spreading behaviour in a non uniformly loaded fabric. Normally quoted in N, KN or LBF.

TEAR STRENGTH

The most confusion reigns over the most relevant of the tear tests commonly quoted in membrane specifications, especially how they relate to actual field performance.

Tongue Tear: Two slits are made in the specimen and a tongue is drawn from the fabric and placed in opposing jaws of the tester. The jaws are drawn apart at a rate of 300mm/min. The Maximum tearing force is quoted in N, KN or LBF.

Wing Tear: Similar to the above test except that only a single cut is made in the fabric and placed in opposing jaws. This is commonly called a Tongue Tear to ASTM Method 5134.

Trapezoid Tear: A slit is made in the side of the specimen perpendicular to the warp or weft direction. The speciman is placed in opposing jaws so that the leading edge of the slit is loaded. Tests to ASTM Method 5136 and DIN 53363 are commonly quoted. Results tend to correlate with strip tensile.

Grab Tear: A special test developed to simulate field performance. Either biaxal or uniaxial, the test involves placing a 25-50mm cut in a specimen of 100-200mm width and measuring the load at which tear propagation takes place.

Tests such as these are commonly quoted in the industry (with the exception of Grab Tear), and form the basis of most membrane selection criteria.

The interpretation of the various specifications quoted by fabric manufacturers is a major exercise. Apart from the differences in dimensional units, the standards have to be compared to see if the test methods are similar.

Ideally, all the fabrics should be tested to a single standard, and this should be a goal of the membrane structures industry.

The chief problem at the moment is that most of the quality fabrics used in Australia have been imported from the USA and Europe, and with the exception of fire testing, there has been no incentive for manufacturers to conduct tests to Australian Standards where they exist. Short Term Properties therefore come with either ASTM, DIN, or BS test results.

A selection of these results is contained in Table 1. For the purpose of comparison, three fabrics have been chosen: a European PVC-Polyester of Class IV rating, an American PVC-Polyester of similar standard, and an American Teflon PTFE-Glass fabric. All three would be used on a fairly large tension structure.

The three represent different approaches to the design of a suitable long life membrane fabric. The European fabric is a heavy 3x3 panama weave, with a very heavy coating to cover the big yarns. It shows high Tensile and Trapezoid figures and high Adhesion to get seam strength. The American PVC-Polyester is a WIWK weave of much lighter weight both base and coated, very high tongue tear strength, and lower adhesion, consistent with WIWK lower stretch characteristics. The American Teflon PTFE-Glass has a high coated weight, high Tensile strength, and very low Tear strength. This is due to the low resilience of the glass fibres and the conventional weave style.

Results for the Grab Tear test were not extensive enough to quote, nor were the seam strengths at 70°. As more experience is gained, the standard test methods quoted should come under greater scrutiny as to their suitability for structural membrane specifications.

They have evolved from the textile industry where fabrics are used in many different ways, and therefore should be interpreted with caution.

The primary loading mode in a membrane structure is biaxial tension, with the possibility of puncture or tearing loads. Essentially, the integrity of the structure is dependent on resistance to propagation of tearing after an environmental loading has penetrated the envelope.

Typically, a combination of tearing modes should be considered. Initially, a Grab Tear would best simulate the fabric under biaxial tension, with a Wing (Tongue) Tear becoming more applicable as the fabric lost tension due to propagation, particularly if wind loads and flutter are involved. Therefore the Grab Tear and Wing Tear results would seem best current indicators of field tear performance.

Work done in the U.K. indicates that for a conventional weave fabric, tear propagation under biaxial load occurs at about 25% of tensile strength. (5)

Table 1.

FABRIC TYPE		Euro Class IV PVC Polyester 3x3 Panama	Shel-Rite 9032 PVC Polyester WIWK	Sheerfill II Teflon Glass Plain
BASE WEIGHT	gsm	490	340	—
COATED WEIGHT	gsm	1300	1090	1530
STRIP TENSILE (Warp/Weft)				
ASTM 5102	N/50mm	7450/6400	5700/5700	7010/6135*
DIN 53354	KN/m	149/128	114/114	140/123 *
	LBF/in	850/730	650/650	800/700 *
GRAB TENSILE (Warp/Weft)				
ASTM 5100	N	N/A	3737/3737	N/A
(25mm Jaw)	LBF	N/A	840/840	N/A
TEAR (Warp/Weft)				
ASTM 5134 Tongue	N	N/A	1334/1334	267/356
BS 3424 (7C)	LBF	N/A	300/300	60/80
TRAPEZOID TEAR (Warp/Weft)				
ASTM 5136	N	1100/1400	623/623	N/A
DIN 53363	LBF	247/315	140/140	N/A
ADHESION				
ASTM 5970	N/50mm	150	87.5	87.5
DIN 53357	KN/m	3.0	1.75	1.75
	LBF/in	17.1	10	10

* Reduce by 12-15% for Flexfold Strength

Figure 1.

RELATIVE SOLAR WEATHERING INDICES IN AUSTRALIA

BASED ON EXPOSURE OF PVC FILMS

LOCATION	R.S.W.I. (n=1) (x 10^4)	(MONTHS) (n=1)	R.S.W.I. (n=2) (x 10^7)	EQUIV. EXPOSURE (MONTHS) (n=2)	AV. EQUIV. (MONTHS)
BRISBANE (Base)	12.0	12.0	7.7	12.0	12.0
SYDNEY	8.46	17.0	5.45	16.9	17.0
MELBOURNE	7.72	18.5	4.49	20.5	19.5
ADELAIDE	13.0	U.1	8.5	10.9	11.0
PERTH	15.53	9.3	9.57	9.8	9.55
HOBART	12.94	11.1	6.79	U.7	12.4
ALICE SPRINGS	18.82	7.6	U.8	6.7	7.15
DARWIN	U.9	10.4	9.38	9.6	10.0
	14.36	10.0	9.29	10.0	10.0
TOWNSVILLE	33.66	10.6	9.16	10.1	10.35

Source: CSIRO Div of Building Research Technical Paper No. 18

Terms: R.S.W.I. (Relative Solar Weathering Index)

R.S.W.I. = $\beta\, \Sigma(fI^n)$ where n=1 or n=2. β = U.V. % of Solar Radiation (Global)
f = Frequency of Exposure (% of total hours)
I = Solar Irradiance (W/m^2)

Assumptions: A linear relationship exists between R.S.W.I. and the Equivalent Period of Exposure. eg. 12 months exposure in Brisbane is equal to 17 months exposure in Sydney.

U.V. RESISTANCE & WEATHERING

It is of the utmost importance that the properties of the fabric be maintained throughout its useful life. Careful selection of raw materials, proper base fabric design, coating compounding and processing are vital to long term performance.

To gain some of solar weathering relativities within Australia, data from CSIRO (1), has been ranked in linear proportion of exposure time to Relative Solar Weathering Index (RWSI) and reproduced in Fig 1. With Brisbane as the base exposure (12 months), the Average Equivalent exposure for other Australian sites are given. eg. 12 months in Brisbane is equivalent to 17 months in Sydney, 10 months in Darwin.

Overseas comparisons can be made on the basis of similar climatic conditions and typically USA based fabrics are tested in Florida exposures as well as with laboratory testing.

The difficulty with laboratory weatherometer testing is always what scale factor applies to real time and real location predictions. Laboratory testing is very useful however for ranking fabric performance, and if field perfromance of one or more fabrics can be correlated to the laboratory tests, valid comparisons can be made. The concentrated mirror weatherometer method (ALTRAC) used at the Allunga Exposure Laboratory, Townsville is a useful example, however the scale factor is still an approximation (4 in this case), and correlation relationships to real time testing are becoming available (2).

Typical test results for real time testing for PVC-Polyester fabric from the USA (Florida conditions) are shown in Fig 2. The fabric in this test result had no acrylic top coating and is still performing now after 20 years exposure.

An approximate correlation using the Atlas Carbon Arc Weatherometer is that 1000 hrs equals 1-2 years in Florida conditions. ie. relatively high U.V. exposure, high temperature and humidity.

Australian experience indicates PVC fabrics performing well after 10 years, in locations as diverse as Sydney and Mt Tom Price in Western Australia.

Predictions of life for any fabric, depend on the definition of 'useful life'. Experience shows that mechanical failure of the base fabric has not been a cause for replacement. Appearance of the coating surface has been the main cause of replacement, and in some cases, the seams have been both aesthetic and structural failures.

Figure 2.

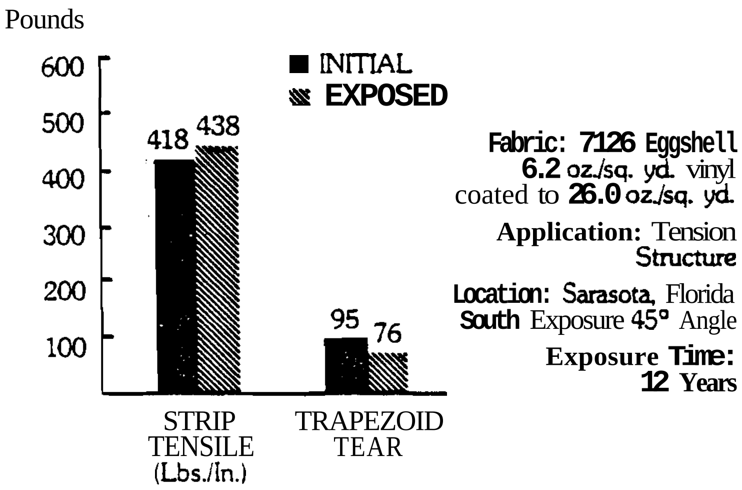
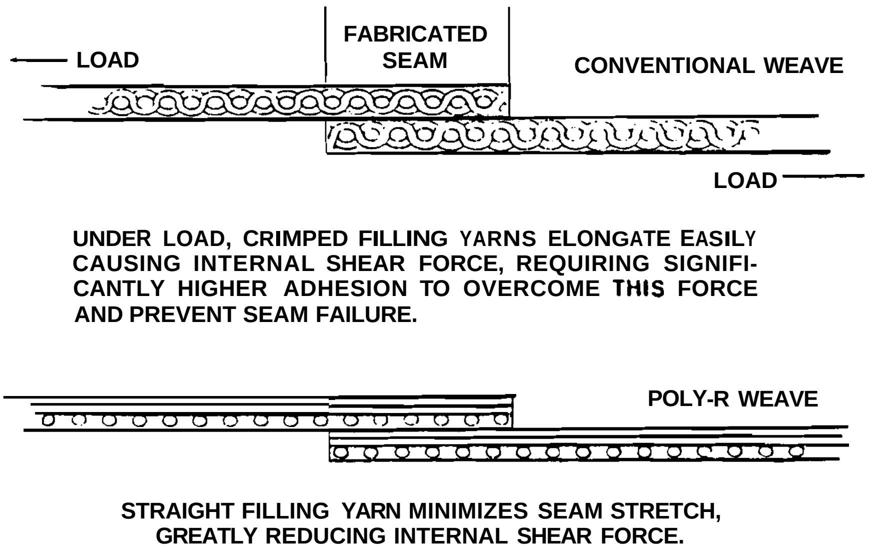


Figure 3.



SEAMING

Adhesion of Coating

The adhesion of the coating to the base fabric is the bond which must be maintained and protected to ensure long life and structural integrity of any tension membrane.

Two types of adhesion occur: mechanical and chemical. Mechanical adhesion is the continuity of coating achieved between the interstices of the weave of loosely woven or WIWK base fabrics with liquid coating systems. Chemical adhesion occurs with primers and adhesives used to form a molecular bond between the fibre and coating or laminate. Ideally, both are desirable to achieve together, but with tightly woven scrim, or laminated coating, only chemical adhesion is present.

It is important to note that chemical adhesion is usually the only bonding process in architectural grades of fabric due to the heavier base yarn required to give adequate strength.

The level of adhesion depends on several factors, chiefly: weave style, coating compound, base fabric treatment, coating process. The adhesion of the coating should be unaffected by the welding process in seaming, and a major factor in seam performance is weave design.

Weave Design

Two basic weave designs have been used for membrane fabrics: 1) Conventional plain or panama weave and 2) Weft Inserted Warp Knit (WIWK) trademarked Poly-R® from Seaman Corporation.

WIWK fabrics have sufficient open interstices to permit a degree of mechanical adhesion to combine with chemical adhesion. WIWK weaves have lower inherent weft stretch due to the straighter lay of the weft (fill) yarn compared with the higher crimping of the weft in conventional weave styles. Figure 3 shows a welded seam made with conventional weave fabric and WIWK fabric. The welded seam of the higher stretch fabric will develop a greater degree of internal shear force within the seam as it begins to stretch under load. A higher adhesion level is required to resist internal shear and preserve seam integrity.

WIWK fabrics are also effectively two yarn layers compared with conventional three yarn layers of conventional fabrics. Apart from reducing the offset of the lines of force in a lap seam, this means a lower coating weight can achieve on WIWK styles, an equivalent or better yarn coverage than heavier coatings on conventional styles.

High Temperature Seam Strength

It is important that the adhesion of the coating to the base yarn and thus the seam strength be maintained at elevated temperatures. In service temperatures (depending on fabric colour) can reach 60-65°C. The dead load test has been developed to check high temperature seam strength. A welded seam is made (of desired width) and a static load applied and held for 4 hours at 70°C. The maximum load before any seam creep or peel failure is measured, and also a peel test for adhesion is made. It is recommended that a 24 hour test period be used for severe climatic conditions of service, and the minimum seam load be used for design purposes.

Caution must be used in interpreting seam strength specifications. High temperature tests are necessary, and the test period must be stated. Snap tests can give results 50-100% of fabric tensile strength for a 50-60mm seam width, whereas a 24 hour 70°C dead load test will give a true result of perhaps 20-30% of fabric tensile strength.

Seaming Techniques

Acrylic coated PVC fabrics can be seamed by high frequency, hot air/hot wedge welding. High frequency welding is always specified for quality membrane structures.

Tedlar® PVF laminated to the face of PVC fabrics in 1-1.5 mil thickness will not readily weld with H.F. equipment. The method usually adopted is to use a PVC fabric tape and double width weld. This has the advantage of leaving a smooth face side at the penalty of extra welding time and cost.

Other methods of removing the Tedlar® from the surface in the seam margin are currently under development.

Wicking Performance

Wicking is the phenomenon of absorbing water through capilliary action by the yarn fibres. The absorbed water can carry micro-organisms which will grow between the coating and the fibres. These micro-organisms can cause stains and with placticized systems, can consume the plasticizer, leading to coating embrittlement and degradation of the yarn fibres.

A simple test has been developed to check if the coated fabric will wick. The test consists of suspending a sample vertically in coloured dye water solution for 24 hours and observing if the dye travels up the yarns. A copy of the test procedure is included as Figure 4. (3)

An example of wicking is shown in Figure 4(A).

Figure **4.**

WICKING OF CLOTH, COATED

1. SCOPE

1.1 This method is to determine the amount of water wicking of coated textiles such as liner fabrics. air-structure materials, truck tarpaulins, etc.

2 TEST SPECIMEN

2.1 The specimen shall be a piece of the finished cloth one inch by eight inches (1" x 8"), cut in the direction specified.

3. NUMBER OF DETERMINATIONS

3.1 Unless otherwrse specified in the material spectfication, one specimen shall be tested from each sample unit.

4. APPARATUS

4.1 Beaker: A one thousand milliliter beaker. Griffin Low Form. The beaker shall be filled to a depth of one inch with a ten percent solution of water soluble dye (contrasting with the color of the material).

4.2 Polyethylene Film: Film of two to twenty thousandths for covering beaker.

5. PROCEDURE

5.1 Hang the specimens along the outside edge of the beaker, with one end just touching the bottom (one inch immersed in the dye solution). Hold in position with a paper clip over the folded surplus over the edge of the beaker. Cover the specimens and beaker with the polyethylene film and hold in place with rubber bands.

5.2 Allow to remain at room temperature for twenty-four hours, unless otherwise specified.

5.3 At the end of the soecified time. remove the specimens. blot off and dry. Observe for stain of cloth: coating may be cut off or peeled to facilitate this.

6. CALCULATION OF RESULTS

The length of wtcking shall be reported. along with the direction.

PURPOSE: To prevent the coated fabric from wicking mpisture and bacteria. Alternated freezing and thawing of wtcked fabric is detrimental to coating adhesion life. Mildew and starn can also occur and decomposed bacteria can be acidic affecting fiber strength and life.

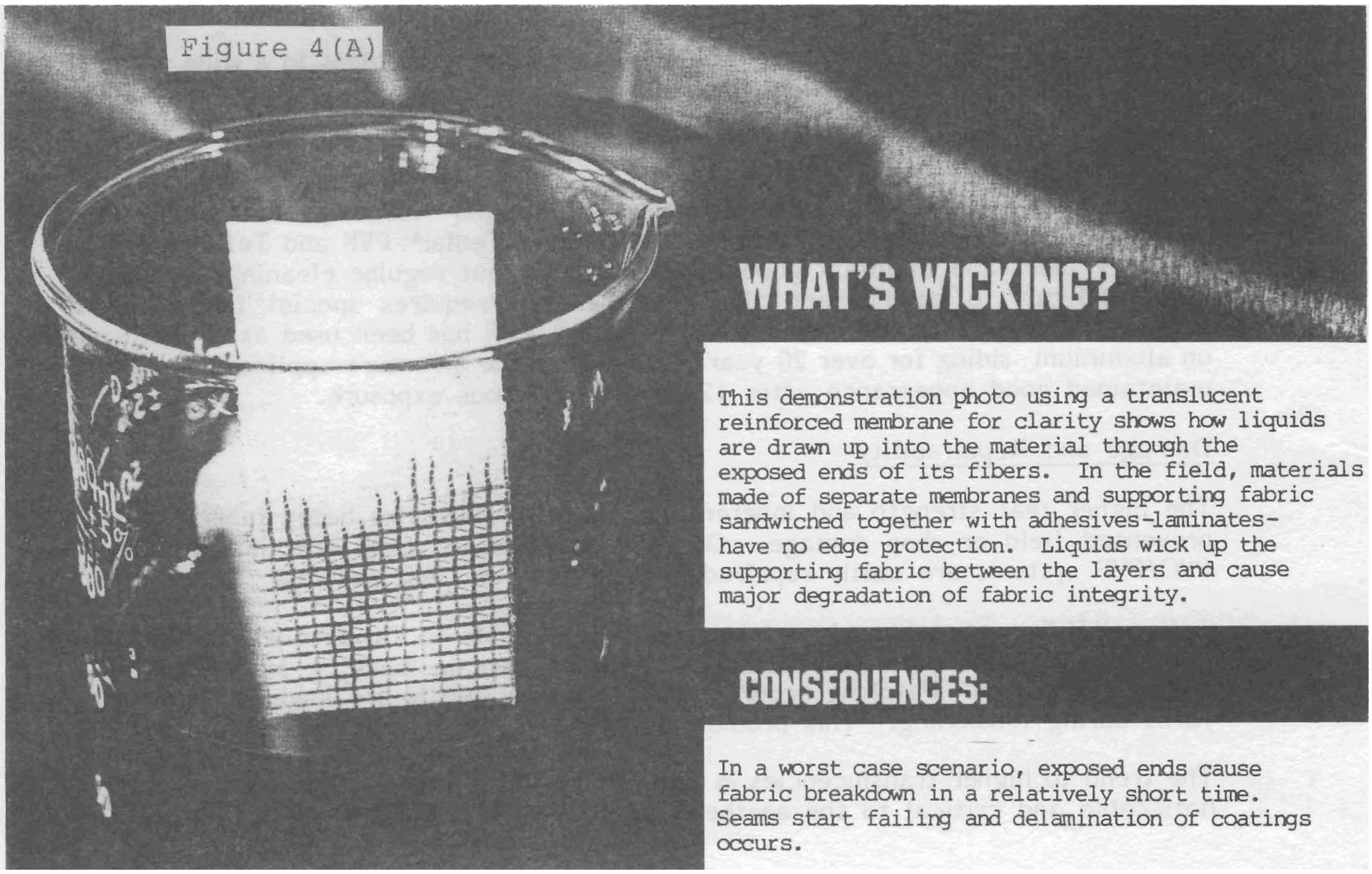


Figure 4(A)

Dimensional Stability

The commonly used base fibres for membrane structures have been polyester and fibreglass. Little data is available on the long term creep performance of these fibres, and field experience shows that initial creep of polyesters causes retensioning of the membrane in 1 - 6 months after initial erection.

Many structures have been installed for up to 10 years without retensioning being required. Present indications are that adjustments made over the first month can remove initial creep sufficiently for no further retensioning to be required.

Weave style has a major effect on the initial stretch behaviour of the fabric. WIWK weaves have diagonal stiffness, making them more stable than plain or panama weave styles. High bias stretch indicates wider seaming along the bias direction to maintain seam strength.

Good dimensional stability is important in the cutting and welding of the fabrics.

Cleanability

Buildup of dirt and pollutants, apart from aesthetic and translucency problems, can damage the coating system and reduce useful life.

Surface coatings on vinyl systems include acrylic lacquers, polymeric films, PVDF lacquers and PVF laminated films.

Teflon PTFE coating on fibreglass has a 16 year history and silicone-glass systems have been used for high translucency applications.

Generally the desirable properties of the surface finish; inertness to a wide range of chemicals, U.V. resistance, flexibility, self cleaning characteristics, are achieved with non-plasticized finishes. These can lead to problems in areas such as handling and fabrication.

Acrylics are suitable for structures where regular cleaning can maintain appearance. They are easy to fabricate and handle. Tedlar® PVF and Teflon PTFE are very inert and maintain good appearance without regular cleaning, but are more difficult to handle, and their inert nature requires special fabrication techniques, especially for teflon-glass. Tedlar® PVF has been used as a coating on aluminium siding for over 20 years, and membrane structure applications have maintained good appearance after 12 years continuous exposure.

Damage and Repairability

The higher tear strength and inherent resilience of polyester based fabrics have prevented field or shop damage. On rare occasions of field erection damage, PVC/PVF systems are easily repaired by adhesives or field welding.

Teflon PTFE coated fibreglass fabrics are susceptable to flexfold weakening of the fibreglass base yarn and require exceptional care in handling in fabrication and field erection. Patching occurs more frequently due to breakage of damaged yarns during tensioning. This problem is unknown in polyester based fabrics.

The trend to higher translucencies in fabric means that field repairs become more noticeable and critical to the aesthetic result.

FIRE RESISTANCE

There are several national standards (DIN, ASTM, NFPA, AS) relating to fire testing, and mostly, they derive from the textile industry for testing membrane fabrics.

In developing the 'Model Code for Architectural Fabric Structures' it was recognized that in spite of the long standing tradition of building terminology such as combustible and non-combustible (and hour fire ratings), and its ingrained use in building codes, its use in relation to fabric structures is misleading. (4)

All the fabrics used for architectural fabric structures, when exposed to a fire, will melt, creating a hole in the fabric. The primary difference is that with 100% polymeric membranes, the hole will be generated quickly, as soon as temperatures exceed 160-250°C. With glass fibre based fabrics, the temperatures must exceed 700°C before they will melt. The melting characteristic has significant benefits in allowing much of the heat and smoke to vent rather than being confined in the occupied space. Glass fibre based fabric will resist fire for a longer period of time, and because of the nature of the materials will contribute less fuel to the fire.

The essential characteristic of fire resistant fabrics is that 'spread of flame' is limited to the source area, and that the fabric self-extinguishes when the source is removed. Also 'smoke developed' must be limited, however for the reasons given above, the smoke is more likely to vent in 100% polymeric fabrics, so is less important in most situations.

Australian Standard 1530 Parts 2, 3, cover flammability of materials and early fire hazard properties.

Comparative results for Tedlar® PVF/PVC Polyester and Teflon PTFE fabrics are shown in Figure 5.

TOXICITY OF FUMES

An issue of concern is the toxicity of fumes developed from non-self venting fabrics such as Teflon PTFE coated fibreglass.

Recently, reports from the U.K. indicate that PVC-Polyester fabrics were specified for the Lords Cricket Ground Grandstand because of a ban on the use of fluoropolymers such as PTFE - glass fabrics for large scale structures. (6).

This is not a problem with Tedlar® PVF PVC Polyester due to the PVF being on the face side of the fabric and PVC on the interior side, which is the only side exposed to any fume development situation.

Figure 5.

FLAMMABILITY OF MATERIALS

FS1530.2.1973		PVF/PVC Polyester Shel-Rite 8028FR 950 gsm	Teflon-Glass Sheerfill II 1530 gsm
Speed Factor	(0-60)	0	0
Spread Factor	(0-40)	1	0
Heat Factor	(0 up)	1	0
Flammability Index		2	0

EARLY FIRE HAZARD

FS1530.3.1973			
Ignitability Index	(0-20)	16	0
Spread of Flame Index	(0-10)	0	0
Heat Evolved Index	(0-10)	0	0
Smoke Developed Index	(0-10)	6	4

Sources: AWTA Test 7-405524-FQ, 7-100411FN, 7-100411FN, 7-100412FN.

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