

THE TRANSFER OF ARCHITECTURAL FABRIC STRUCTURE MEMBRANE TECHNOLOGY TO HIGH PERFORMANCE ROOFING MEMBRANES

RICHARD N. SEAMAN

Seaman Corp.
Millersburg, Ohio

In the last decade, the single-ply roofing concept has made significant contributions to current roofing technology. Although single-ply roofing has been used for more than 25 years in this country, only in the last 10 years has this product enjoyed a significant share of the roofing market. Its rapid growth can be attributed to a number of factors.

The rise in oil prices in the early 1970s resulted in a significant cost increase for built-up roofing materials. The quality of the materials supplied from the refining process deteriorated as more of the oil was refined to increase gasoline yield. The quality of the felts used in built-up roofing became poorer as competitive pressures forced the traditional materials out of the market. The labor intensity of the built-up roofing process increased the cost and affected ongoing quality of applications. The net results were that the longstanding traditional four-ply built-up roof became more expensive, and its performance deteriorated.

The more costly, poor performing built-up roofing system became the fertile ground for the seeds of the single-ply roofing revolution. In the last five years, the growth of single-ply roofing has exceeded even the most optimistic projections. In 1980, single-ply roofing enjoyed 10 percent of the 2.1-billion-square-foot flat deck roofing market. At that time, it was projected that by 1985, it would grow to 23 percent of a 2.4-billion-square-foot market, or 550 million square feet. In reality, in 1984, the total single-ply roofing market should exceed 750 million square feet.

Another reason for this significant growth is the rapid advance that has been made in membrane technology for single-ply roofing. Obviously, with the market size and growth experienced in recent years by the single-ply roofing market, many new companies and materials have been introduced. Most of these single-ply materials can be categorized in four areas.

Modified bitumens use material similar to that traditionally found in four-ply built-up roofs but are combined in a factory environment and shipped to the job site in roll form.

Synthetic rubbers such as EPDM and neoprene have a history of long-term performance in single-ply roofing. The technology of these polymers was developed from the rubber industry, specifically from those companies with a great deal of experience in the tire industry.

Plastic membranes, such as polyvinyl chloride, also have a history in the single-ply roofing market. This technology was developed from the plastics industry because polyvinyl chloride films are used for a multitude of applications.

Many PVC membranes were introduced from a variety of product industries. Some of these industries were not familiar with the high demand of single-ply roofing performance and many of these membranes did not meet the long-term performance criteria.

Thermoplastic elastomers, which represent new polymer technology, have been recently introduced for high-performance roofs. These would include products such as chlorinated polyethylene (CPE); Hypalon®; and ethylene interpolymers (EIP).

Most of the membranes mentioned above were initially introduced as unsupported films. The thickness of these films ranged from 30 mils to 65 mils and more. In recent years, the performance of these films has been enhanced with the addition of reinforcement fibers, generally in the form of open-weave, polyester scrim materials.

Materials development in an emerging fast-growth market is always an evolutionary process. Materials are introduced and refined based on the performance experience in actual application and on the impetus of cost competitiveness as a result of competition entering the marketplace. The evolution of materials development in the single-ply roofing market will certainly be a classic case. New materials and technology are being introduced into this marketplace faster than the members of the industry can comprehend and more rapidly than adequate performance specifications can be written.

One of the more interesting evolutionary developments of single-ply roofing membranes is the transfer of the technology that has been developed for membranes used in architectural fabric structures. Single-ply membranes have been used in architectural fabric structures for more than 30 years. These applications are very rigorous because the single-ply membrane is actually the structural roof. Generally, these membranes have high fiber reinforcement content and very unique performance properties. These unique performance properties have developed in architectural fabric structure membranes because these membranes are under constant tension and are exposed to a wide variety of climatic and environmental conditions. This rigorous exposure has resulted in membrane performance properties that make them natural candidates for high-performance single-ply roofs.

There are two basic types of architectural fabric structures: air-supported structures and tension-membrane struc-

® Registered trademark of the DuPont Co.

tures. Air-supported fabric structures rely only on internal air pressure to maintain their inflated shape and their structural design. Tension-membrane structures utilize a single-ply membrane that is tensioned over a frame or cable network to achieve their structural integrity and shape. Both types of structures have been used for such traditional applications as warehousing, recreational facilities and military uses.

In addition, much more dynamic and contemporary applications are being found for this building concept. As an example, the Los Angeles International Airport has used three large air-supported structures to provide passenger servicing space for the U.S. Customs. Several branches of the armed forces are utilizing 20,000-square-foot tension-membrane structures to provide dehumidified warehousing space for military equipment in locations all over the world. The fabric structure concept is being used successfully by shopping malls and department stores to provide a unique daylight roofing system.

These dynamic applications require high-performance fabric membranes to provide long-term, watertight weather performance and good aesthetics in a wide variety of environmental conditions. These demands have resulted in the development of fabric membranes that have very unique performance properties. Following is a brief description of those performance properties that impart long service life in architectural fabric structure applications, and a discussion of the significance of these properties to the single-ply roofing product.

HIGH TENSILE AND TEAR STRENGTHS

The roof of an architectural fabric structure must be designed with very high tensile and tear strengths because it is composed solely of membrane material. Tensile strength is required to meet design and engineering criteria for the internal air pressure supporting the structure, or for the stresses applied to a tension structure. Tensile strength is also necessary to withstand external wind forces that will affect the structure and stresses that will be caused by snow loading. High tear strength is necessary to prevent punctures from propagating into major structural tears. The actual performance life of an architectural fabric structure can be significantly affected by the tensile properties of the membrane. The use of high-tensile yarns woven into contemporary weave designs has significantly improved the tear properties of fabrics in the past decade. Tensile strengths in excess of 300 pounds per inch will provide tear strengths higher than 100 pounds. The combination of good tensile and tear properties also provides excellent puncture resistance to the membrane.

These tensile and tear properties are important to single-ply roofing. A reinforced membrane with high tensile strength permits the use of unique mechanical fastening techniques to attach the membrane to the roof deck. Fastening systems such as those illustrated in the photographs provide wide fastener spacing and quick, economical installation in a multitude of roof and climatic conditions. High tensile properties will prevent the membrane from ripping out of the fastener when high wind uplift forces are applied to the roofdeck. Puncture resistance is very important to help the single-ply roof membrane withstand roof traffic or maintenance activities around mechanical equipment. High

fiber content will improve weatherability and provide significantly longer outdoor life to a single-ply membrane that is susceptible to rigorous exposure.

EXCELLENT COATING ADHESION

Adhesion of the coating system to the base fiber is a significant quality consideration, and one that has achieved high levels of technological development in architectural fabric structure applications. The coating system protects the strength of the yarn fibers for many years. However, if this coating does not have good adhesion to the fiber it can be abraded or may actually delaminate after several years, exposing the yarn fibers to the environment. The adhesive system utilized is a key factor in providing excellent abrasion resistance to the membrane.

Excellent coating adhesion is a primary requirement for achieving necessary seam strengths. The high tensile properties imparted in the fabric membrane will be lost in actual application if those same tensile properties are not present in the welded seams that join the fabric panels together. The tensile properties of factory and field seams should be equal to or greater than the tensile strength of the fabric itself. These seam characteristics must also be maintained in a wide variety of environmental exposures over many years. The seam strength must not deteriorate when exposed to moisture.

This quality of seam adhesion must be maintained at elevated temperatures. In some cases, adhesion systems will provide adequate seam strength at room temperature but when exposed to a high temperature environment, seam slippage will occur. On a hot, sunny 95F day, the surface temperature of a dark-colored panel in a fabric structure can reach as high as 165F. The seam strength must be maintained at these high temperatures. Adhesive systems have been developed which will retain their strength under load when exposed to temperatures of 165F.

Quality adhesion of the coating system to the reinforcement fiber is very important in single-ply roofing membranes. All roofing systems are susceptible to expansion and contraction. This action will impose stress on both factory and field seams on a roof deck. Seam slippage must not occur when these stresses are applied. Dark roof decks will reach very high surface temperatures on a hot, sunny day, and the seam strength must withstand the load at that temperature. Water ponding is a common phenomenon on a roof deck. The seams are exposed to high moisture environments, many times at elevated temperatures. A quality adhesive system will provide long-term performance of factory and field seams when exposed to these conditions.

A quality seam adhesion system, particularly for a thermoplastic membrane, will permit factory and field seams to be manufactured without introducing an adhesive or solvent element. This simplifies the seaming process and gives greater assurance of long-term seam performance.

NON-WICKING

This characteristic determines whether moisture will travel through the yarns of the base fabric if exposed to water. If moisture does wick through the yarn system of a fabric structure membrane, freezing and thawing of this moisture will cause deterioration of the fiber strength. In addition,

wicking will also provide a moist atmosphere for mildew growth, which can further deteriorate fiber and seam strength. Quality coating and adhesive systems will prevent the wicking of moisture through reinforcement yarns.

The non-wicking performance requirement is very critical to single-ply roof decks. Flat deck roofs are exposed to high quantities of water. Unlike most architectural fabric structures, which are designed to shed water and avoid ponding, flat deck roofs often hold water for long periods of time. If the edges of the single-ply roofing membrane do not exhibit non-wicking characteristics, the water moisture will seep through the yarns into the membrane. This moisture environment can affect the coating or cause seam failure. Freezing and thawing conditions, will also significantly deteriorate the strength of the fiber. A wet membrane can serve as a warm, moist medium for fungus and mildew growth, which will significantly affect the coating system and reduce the performance of the membrane.

Many single-ply roofing membranes today do not exhibit non-wicking characteristics. After seams are manufactured, either in the factory or on the roof deck, the roofing contractor must go over the edges of the seams with a caulking compound to assure that moisture will not wick into the yarn system. A membrane that exhibits non-wicking performance properties eliminates this application and provides for a more economical and reliable installation procedure.

DIMENSIONAL STABILITY

The dimensional stability of a membrane used for architectural fabric structures can significantly affect the design and patterning of air and tension structures. Low-stretch characteristics are designed for membranes used as structural building materials. In the early history of fabric structure development, nylon-based fabrics were used extensively. Nylon exhibits high elongation characteristics, which complicate the design and installation of structures. For example, a 300-foot air-supported structure would have stretch properties that would impart a 10 percent elongation in the fabric membrane at the desired inflation pressure. As a result, the structure must be designed 30 feet short of its ultimate length so it will achieve its desired length after inflation. This elongation characteristic has been improved significantly in recent years by selecting polyester yarns and utilizing contemporary weave designs. Elongation properties have been improved by as much as 50 percent.

In tension-membrane structures the dimensional stability of the membrane is far more critical because the design, engineering, and patterning are more complex than in air-supported structures. Excessive fabric stretch will complicate the engineering process. In addition, the structure's loading characteristics, shape and aesthetics depend upon uniform precalculated tensioning of the fabric. The dimensional stability of the membrane must be predictable and uniform and must not change when climatic conditions change.

Polyester is the preferred fiber. For example, a nylon panel that is 200 feet long can change as much as 8 inches in length overnight if temperature and humidity conditions change. A polyester-based fabric panel of the same length will only change $\frac{1}{4}$ inch under similar conditions.

The dimensional stability of single-ply roofing membranes is very critical. There are many cases in which large

areas of membrane are placed on roof decks and left in a relaxed mode. When environmental conditions such as temperature or humidity change, it is important that the membrane does not change its dimensions. A change similar to that of the nylon panel described above will cause excessive loads at fastening locations, possibly tearing the membrane away from its fastening area and resulting in water leakage.

Elongation characteristics are also important in single-ply roofing. Because flat-deck roofs are under constant movement from expansion and contraction due to environmental changes, they impart stresses on the membrane itself. If these stresses are concentrated or localized, elongations of 100 percent or more could be experienced. However, if the roofing system is designed so that roof deck movement forces are dissipated over larger areas of the roofing membrane and not concentrated in one small area, polyester-based fabrics exhibit enough elongation to absorb these forces. Polyester fibers will elongate as much as 20 percent before breaking. This amount is more than adequate for a well-designed application system.

FLAME RESISTANCE

In architectural fabric structure applications, the fabrics' flame-resistance is very important. Flame-resistant characteristics have been scrutinized by building code officials and fire protection agencies to assure excellent life-safety performance. Most of the membranes that are utilized in architectural fabric structures have been designed to meet the NFPA-701 Flame Resistant Test. This particular test is a two-second self-extinguishing requirement recognized by the military, the National Fire Protection Association and major building code agencies. Fabric building materials that meet this specification and have experienced actual fire exposures have performed excellently.

Flame resistance is also a significant concern in single-ply roofing products. However, because the membrane is only one element of a total flat-deck roofing system, the test criteria are not as rigorous. It has been found that membranes which will meet a military test, MIL-C-20696C, Type II, Class 2, wherein the membrane is exposed to a flame source for 12 seconds and must not be consumed within a period of 30 seconds, achieve excellent fire performance. When combined with metal decks and properly classified insulation, these single-ply roofing membranes can achieve a Class A rating without the use of ballast.

RESISTANCE TO FUNGUS AND MILDEW GROWTH

Many architectural fabric structures are utilized in warm, moist environments. If the fiber and coating cannot resist fungus or mildew growth, such growth will affect not only the aesthetic appearance of the structure but also the strength of the fabric.

Single-ply roofing membranes are also exposed to warm, moist environments. Contaminants from the atmosphere often settle on these flat-deck roofs and can serve as a medium for fungus and mildew growth. It is important that the single-ply roofing membrane have excellent resistance to growth of fungus or mildew.

WELDABILITY

In the development of fabric membranes for the architec-

tural fabric structure market, the weldability of the membrane is important for the ease and economics of seam fabrication. It also facilitates repair in the field.

Excellent weldability characteristics in a single-ply roof membrane improve the economics of factory and field seams. Ease of weldability increases installation efficiency and improves the reliability of seam performance in long-term applications. The weldability characteristics should remain a property of the membrane even after years of outdoor exposure so that repairs can be made easily.

AESTHETIC APPEARANCE

The aesthetic appearance of an architectural fabric structure is one of its strongest appeals. Fabric membranes used in architectural fabric structures generally have the ability to be manufactured in a multitude of colors. Unique finishes or claddings are applied to the fabric to assure easy cleaning over a long period of time.

Light-colored membranes are important to the single-ply roofing market because they reflect the sun's rays and provide cooler environments. It has been proven that the light-colored membranes will provide significantly improved energy savings in the maintenance and management of a building over black roofing systems.

CHEMICAL RESISTANCE

Architectural fabric structures are exposed to a wide variety of atmospheric conditions. Not only are they exposed to a wide range of climatic changes, but their locations around the world expose them to areas of high atmospheric contamination. Membranes that have been developed for fabric structures exhibit chemical-resistant properties and permit them to maintain their long-term outdoor performance even though chemical contaminants may rest on the surface.

Single-ply roofing applications have even more critical chemical exposure requirements. In many cases, the atmospheric contaminant is generated at the roof deck itself. Examples include oils which condensate near a roof stack or animal fats from the vent stack of a restaurant. These chemical contaminants will cause many membranes to deteriorate rapidly and leak. However, technology developed from architectural fabric structure membranes combined with technology that has been developed for pit and pond liner applications provides membranes for the single-ply roofing market that will resist chemical contaminant exposures.

EXTENDED LIFESPAN

The design and engineering that goes into architectural fabric structures represent a significant investment. Architectural fabric structures must provide quality performance properties for a period of 15 to 20 years. With the technological improvements that have been made in these membranes in recent years, a service life of 15 to 20 years can certainly be anticipated.

As an example, a tension-membrane structure is pictured that has been in application for over 16 years and utilizes a vinyl-coated polyester-base fabric. The location of this structure is in Sarasota, Fla., which has one of the highest ultraviolet light exposures in the country.

During the twelfth year of exposure, a sample of fabric

was removed to test its performance characteristics. The material was still flexible and watertight. The chart indicates the strength retention properties of this membrane. After 12 years, it retained more than 90 percent of its tear and tensile properties. An examination after 16 years of exposure indicates no significant change in the performance capability of this membrane. It should certainly provide a minimum 20 years of watertight performance in this application.

Obviously, a roof deck investment in a building is significant and the building owner expects long-life performance. Membranes which exhibit the kinds of properties demanded by architectural fabric structure applications, where the membrane is the roof, will provide 15 to 20 years of watertight performance in flat deck roofing applications.

Performance properties developed for membranes utilized in architectural fabric structures can be achieved by the proper selection and design of the base fabric and the coating system.

Through years of experience in architectural fabric structure applications, the development of a base fabric has evolved. Although fiberglass, nylon, polyester and other more exotic yarns are available, most architectural fabric structures today utilize polyester fibers. Polyester is the yarn of choice for the following reasons:

- The high modulus of the yarn minimizes elongation under load.
- Polyester yarns have excellent dimensional stability in humidity and temperature changes.
- Polyester yarns have excellent chemical resistance, particularly when exposed to an acid environment.

The polyester yarn is utilized in one of the more contemporary weave designs known as Weft Inserted Warp Knit (WIWK). Conventional weaves interlace the warp and weft yarns. In the WIWK fabric formation system, weft yarns are laid on top of warp yarns and held together by a very fine stitching yarn. This is an efficient fabric formation technique. More importantly, fabrics manufactured with this technique exhibit better dimensional stability and much higher tear strength for a given tensile strength.

There are numerous coating systems available to apply to the WIWK polyester base fabric, including Hypalon, CPEs, urethanes, neoprenes and polyvinyl chlorides. Traditionally, plasticized PVC has become the most popular and versatile for architectural fabric structure applications. Advantages of the plasticized PVC coating include the following:

- easy processing with conventional thermoplastic equipment;
- good chemical resistance to diluted acids, plating solutions, salts, and other chemical environments;
- excellent outdoor weatherability when properly formulated;
- accepts coloring very easily;
- as a thermoplastic, can be fabricated easily by thermal sealing, high frequency sealing or adhesive bonding; and
- the system is very economical and has an excellent balance of properties.

In recent years, the excellent properties of a polyvinyl chloride polymer system has been enhanced even further by blending it with new thermoplastic polymers that are available on the market. When an ethylene interpolymer is

combined with the PVC polymer, all of the advantages of the plasticized PVC are retained, and even longer life and improved chemical resistance are provided because the loss of plasticizer is prevented.

Most high-performance architectural fabric structure applications utilize fabrics that are coated rather than laminated. While lamination processes are highly efficient, they have some severe limitations when trying to impart a multitude of performance properties to the membrane. Coated fabric systems permit the use of more tightly woven base fabrics. They offer more flexibility and design uniqueness in the adhesive systems. Although their multiple pass requirement is more costly than the high-speed lamination processes, quality characteristics that can be imparted in a coated fabric system far offset the economic disadvantages, particularly when manufacturing a membrane that requires a 20-year service life.

The revolution continues to occur in the single-ply roofing market. The satisfactory performance of this building concept will continue to increase its growth and popularity. These market opportunities will see the introduction of many new membranes and systems as performance data is gathered and as competitive pressures force changes in existing membrane materials. However, it is fortunate that this marketplace has an opportunity to share in the technology of an associated market area that has more than 30 years of actual experience. Architectural fabric structures are viable building concepts that have demanded the development of materials providing 20 years of excellent outdoor weather performance, with the membrane itself being the roof. An examination of this technology and utilization of these material properties will assure a single-ply roofing system the standard of the industry once again.



Figure 1 Garden State Paper Company. This 100,000-square-foot tension membrane structure has more than seven miles of seams under a constant tension of 60 pounds per foot. The membrane is exposed daily to high concentrations of atmospheric pollutants.



Figure 2 Los Angeles International Airport. This is one of three air-supported structures that were used by the U.S. Customs Bureau until permanent structures could be erected.

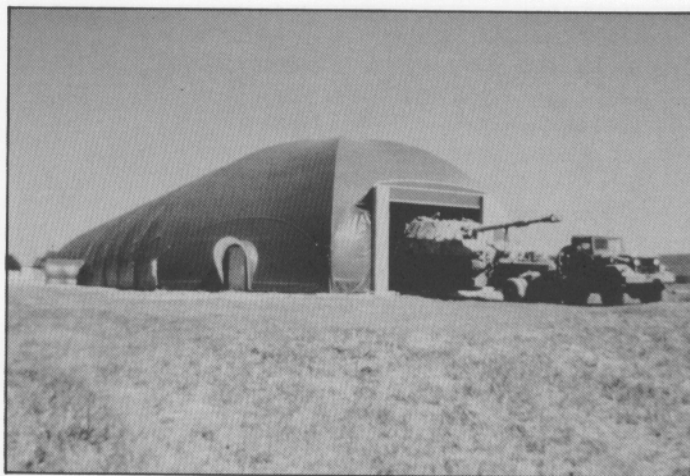


Figure 3 Military Portomod® is one of twenty-six 20,000 square foot tension membrane structures used by the U.S. Army to provide dehumidified warehouse space for the long-term storage of equipment

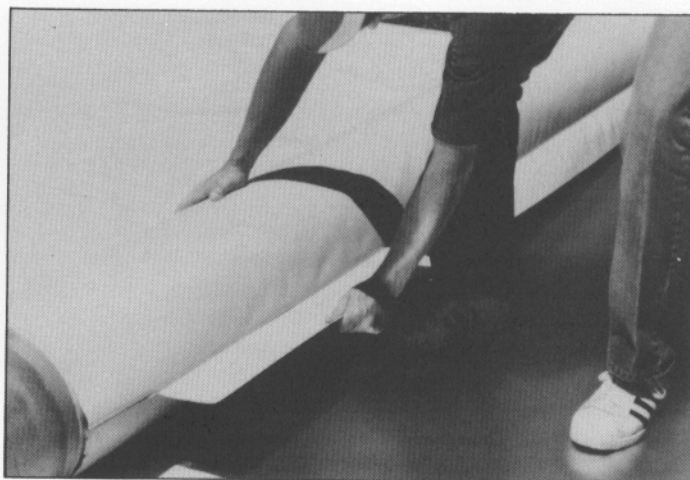


Figure 4 Unique fastening tab system combines strength with speed of installation, eliminates fastener penetration of finished roof

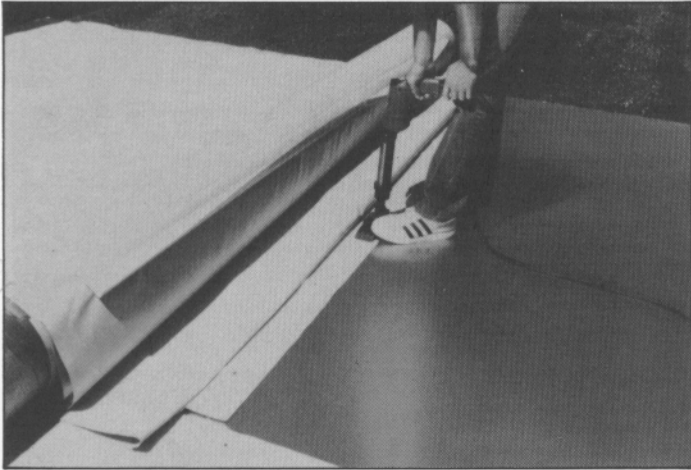


Figure 5 Fasteners 18 inches on center secure tab to roof deck using conventional fasteners



Figure 6 Wagon Ho Restaurant roof has endured the highest ultraviolet concentrations in the United States for more than 16 years without loss of structural integrity

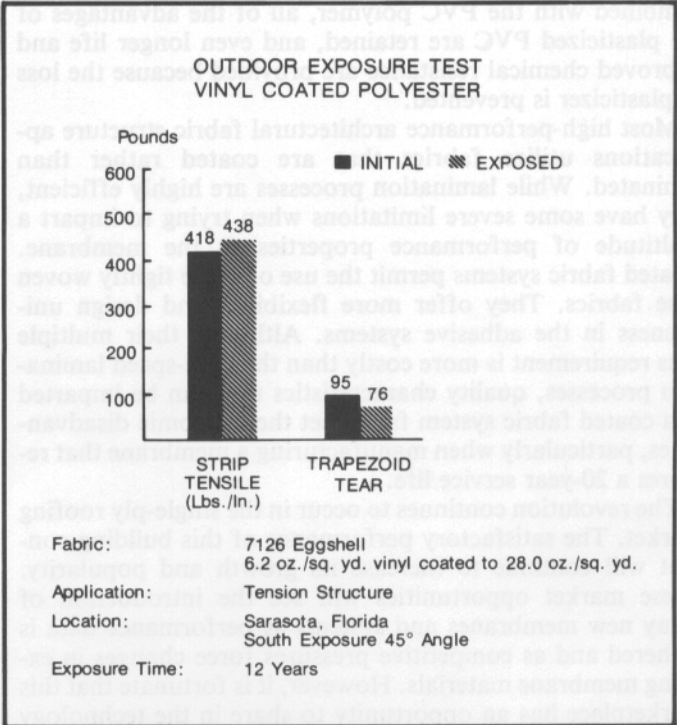


Figure 7 Twelve-year field exposure of membrane in Sarasota, Fla. shows only minor loss of tear and tensile properties